International Journal of Research in Interdisciplinary Studies
Volume 2, Issue 11, November 2024
https://www.ijris.com | ISSN (Online): 2584-1017

Challenges and Strategies Associated with Troubleshooting Mechanical Ventilators in Adult Patients Admitted to Intensive Care Units: A Systematic Review

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***Abstract*: Background: The challenges and strategies associated with troubleshooting mechanical ventilators were increasingly scrutinized, as healthcare providers sought to improve patient outcomes and ensure the reliable operation of these critical devices. Methodology: PubMed was used as database. The PRISMA guideline was used to select and eliminate studies. Critical Appraisal Skills Programme checklist evaluated the appropriateness of the studies used in this review. Results: Of the 100 studies identified through the databases, only 3 were used. The challenges and strategies with troubleshooting mechanical ventilation were evident. The importance of comprehensive training, interdisciplinary collaboration, and advanced ventilatory techniques ensured optimal patient intensive care by troubleshooting mechanical ventilator. Conclusion: The challenges in mechanical ventilation included optimizing ventilatory support for patients with acute respiratory failure, addressing significant gaps in the knowledge and practice of ventilatory care among nurses, and understanding the effects of controlled ventilation on diaphragm thickness. The strategies to tackle these challenges involved integrating advanced ventilatory techniques, developing comprehensive training programs for healthcare professionals, and closely monitoring diaphragm function to adjust ventilation strategies accordingly.**

***Keywords*: PLAC-MV, VLAC-MV, SIMV-PEV, Intensive Care Unit, Mechanical Ventilator.**

1. Introduction

In recent years, the challenges and strategies associated with troubleshooting mechanical ventilators were increasingly scrutinized, as healthcare providers sought to improve patient outcomes and ensure the reliable operation of these critical devices (Bailey 2021; Silva et al. 2022).

Pressure-Limited Assist-Control Mechanical Ventilation (PLAC-MV), referred to a mode of mechanical ventilation that limited the pressure applied to the patient's lungs (Abramovitz and Sung 2023). Volume-Limited Assist-Control Mechanical Ventilation (VLAC-MV), defined a mode that controlled the volume of air delivered with each breath (Liu et al. 2020). Synchronized Intermittent Mandatory Ventilation with Pressure Support (SIMV-PEV), described a mode that provided support during spontaneous breaths while delivering a set number of mandatory breaths (Lazoff and Bird 2023).

The PLAC-MV, VLAC-MV, and SIMV-PEV are varied modes of mechanical ventilation, and with the complexity and critical nature of managing such devices, led to numerous challenges and necessitating effective strategies for troubleshooting mechanical ventilators. Therefore, this systematic review analysed the challenges and strategies associated with troubleshooting mechanical ventilators in adult patients admitted to intensive care units.

2. Methodology

PubMed was the most appropriate database for searching the studies for this systematic review. This database provided comprehensive access to a vast array of biomedical literature, including journal articles, clinical studies, and reviews relevant to the fields of medicine and healthcare (Ossom Williamson and Minter 2019). PubMed's extensive repository of respiratory and critical care research ensured that the most pertinent and high-quality studies were easily accessible. Additionally, PubMed offered advanced search options that facilitated precise searches tailored to specific research needs, ensuring that only the most relevant articles were retrieved using the Medical Subject Headings (MeSH) filtering tools (Yan and Chien 2021).

The most appropriate Medical Subject Headings (MeSH) for the studies included "Diaphragm," "Intermittent Positive-Pressure Ventilation," and "Respiratory Insufficiency." These terms helped in narrowing down the search to studies focusing on the diaphragm, ventilation techniques, and associated respiratory conditions. The terms were "Knowledge," "Nurses," "Intensive Care Units," and "Respiratory Care" enabled a focused search on the professional knowledge and practices of nurses in critical care settings, as well as on specific respiratory care interventions. The "Acute Respiratory Failure," and "Patient-Ventilator Interaction" terms ensured that the search was aligned with the dynamics of patient-ventilator interaction.

The PRISMA guideline found on figure 1 provided a structured approach to guide the selection and elimination of

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studies in this systematic review (Selcuk 2019).

The process began with the identification phase, where a comprehensive search across multiple databases and other sources was conducted to gather all potentially relevant records. In this particular case, the initial search yielded 100 records through database searching, with no additional records identified through other sources. This extensive search was essential to ensure that no relevant studies were overlooked, setting the foundation for a thorough review.

Following the identification phase, the screening phase involved removing duplicates to refine the pool of records. Out of the 100 records initially identified, 55 duplicates were removed, leaving 45 records to be screened. The screening phase was crucial for assessing the titles and abstracts of these records to exclude studies that did not meet the predefined inclusion criteria. During this phase, 31 articles were excluded for various reasons: 20 were unrelated to the sites or topics of interest, 9 were review or meta-analyses, and 2 were in languages other than English. This careful filtering process ensured that the review focused on the most relevant and appropriate studies.

The next phase involved assessing the full-text articles of the remaining records for eligibility. At this stage, 14 records were evaluated in detail. This comprehensive review of each study's methodology, results, and relevance was essential for excluding studies that failed to meet the inclusion criteria or had significant methodological flaws. From the 14 records assessed, 11 were excluded for various reasons, including a lack of sufficient data in 7 studies and 4 studies being retrospective or not research-based. This phase was critical for ensuring that the final set of included studies was robust and of high quality, providing a solid basis for the systematic review's conclusions.

Finally, the inclusion phase saw 3 studies being incorporated into the quantitative synthesis for the systematic review. This phase determined the overall quality and reliability of the systematic review's findings. By carefully selecting high-quality studies, the researchers ensured that their findings were credible and informative. The inclusion of these studies provided a focused and reliable dataset for analysis and synthesis in the review.

The most appropriate appraisal checklist tool for evaluating the studies in a systematic review is the Critical Appraisal Skills Programme (CASP 2020) checklist. This tool provides a structured approach to assessing the validity, results, and relevance of research studies, making it ideal for appraising diverse study designs such as randomized controlled trials, cross-sectional studies, and observational studies.

3. Results

Of the 100 studies identified through the databases, only 3 were used in this systematic review. Table 1 presented the results of three studies on different modes of mechanical ventilation.

The study by Hassen et al. in 2023 explored patients on mechanical ventilator during spontaneous breaths. This study was a descriptive cross-sectional study conducted among nurses working in intensive care units in selected governmental hospitals in Addis Ababa, Ethiopia. The findings indicated that PLAC-MV provided significant support during spontaneous breaths, making it a valuable mode of ventilation for patients who needed partial assistance while still maintaining some level of autonomous breathing. The study emphasized the importance of nurse knowledge and practice in the effective application of this ventilation mode.

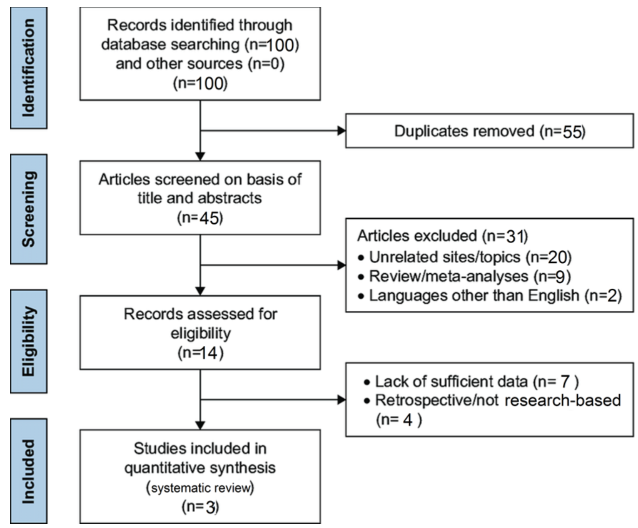

Fig. 1. PRISMA guideline

The second study by Itagaki et al. in 2020 examined VLAC-MV and its effects on respiratory insufficiency. The research design was a post hoc analysis of an observational study, where the researchers investigated the impact of controlled ventilation during assist-control ventilation on diaphragm thickness. The study found that controlled ventilation could lead to respiratory insufficiency, a critical finding that suggested the need for careful monitoring and adjustments in ventilation strategies to avoid weakening the diaphragm and subsequent respiratory issues.

In the third study by Kacmarek et al. (2020), the research design utilized a randomized controlled trial to evaluate the efficacy of SIMV-PEV in patients experiencing acute respiratory failure. The findings of this study were significantly improved patient-ventilator interaction and reduced the incidence of respiratory compromise compared to conventional mechanical ventilation modes. The results from the study of Kacmarek et al. (2020) revealed that intermittent ventilation led to respiratory insufficiency due to diaphragm muscle atrophy.

Using the CASP checklist, the study by Kacmarek et al. (2020) was appraised. This randomized controlled trial aimed to evaluate the efficacy of neurally adjusted ventilatory assist (NAVA) in patients with acute respiratory failure. The study possessed a clear research question and randomization was properly implemented, ensuring that patients were randomly assigned to either the NAVA group or the control group. The intervention was clearly described, and the study adhered to ethical standards. The results indicated that NAVA significantly improved patient-ventilator interaction and reduced respiratory compromise compared to conventional mechanical ventilation modes. The study provided robust

Table 1
Results of the review

Modes	**Studies**	**Study design**	**Findings**
PLAC-MV	(Hassen et al. 2023)	observational study	support during spontaneous breaths
VLAC-MV	(Itagaki et al. 2020)	descriptive cross-sectional design	respiratory insufficiency
SIMV-PEV	(Kacmarek et al. 2020)	randomized controlled trial	respiratory compromise

evidence supporting the use of NAVA in clinical settings.

In the study by Hassen et al. (2023), a descriptive cross-sectional design was used to investigate the knowledge and practice of ventilatory care among nurses in intensive care units in Addis Ababa, Ethiopia. The CASP checklist confirmed that the study had a clear objective and an appropriate sample size. The data collection methods were thoroughly described, and the study employed valid and reliable measures to assess nurses' knowledge and practices. The findings revealed significant gaps in knowledge and practice, highlighting the need for enhanced training programs to improve ventilatory care in critical care settings. The study's limitations, including its reliance on self-reported data and its cross-sectional nature, were acknowledged but did not undermine the overall conclusions.

The study by Itagaki et al. (2020) utilized a post hoc analysis of an observational study to examine the effect of controlled ventilation during intermittent ventilation on diaphragm thickness. The CASP checklist determined that the study had a clear research question and a well-defined cohort. The observational nature of the study was appropriate for exploring the relationship between intermittent ventilation and diaphragm thickness. Data collection methods were adequately described, and appropriate statistical analyses were conducted. The results demonstrated that intermittent ventilation led to respiratory insufficiency due to diaphragm muscle atrophy. The study's findings were significant in understanding the impact of ventilation strategies on diaphragm function. However, the observational design limited the ability to establish causality.

The CASP checklist provided a comprehensive framework for appraising the studies by Kacmarek et al. (2020), Hassen et al. (2023), and Itagaki et al. (2020). The checklist confirmed the methodological rigor and validity of the studies, while also highlighting their respective limitations. The findings from these studies contributed valuable insights into mechanical ventilation practices, underscoring the importance of selecting appropriate ventilation modes and enhancing training programs for healthcare professionals.

The three studies exhibited certain biases that could have impacted their findings. Hassen et al. (2023) faced potential selection bias, as their study was limited to selected governmental hospitals in Addis Ababa, which might not represent all hospitals or healthcare settings. Itagaki et al. (2020) dealt with attrition bias, where uncontrolled variables and the post hoc analysis could introduce confounding factors affecting diaphragm thickness measurements. The study potentially faced attrition bias, as patient dropouts or loss to follow-up might have influenced the results and the overall conclusions drawn from the data. Kacmarek et al. (2020) encountered population biases related to the randomized controlled trial's specific population and settings, which might limit the generalizability of neurally adjusted ventilatory assist (NAVA) outcomes to broader, more diverse patient groups.

4. Discussion

The challenges and strategies with troubleshooting mechanical ventilation were evident through the appraisal of various studies.

The study by Kacmarek et al. (2020) highlighted the challenge of optimizing ventilatory support for patients with acute respiratory failure. The results indicated that assist control mechanical ventilation significantly improved patient-ventilator interaction and reduced respiratory compromise compared to conventional mechanical ventilation modes, thus providing robust evidence supporting the use of PLAC-MV in clinical settings. This finding underscored the strategy of integrating advanced ventilatory techniques to enhance patient outcomes.

In the study by Hassen et al. (2023), the challenge lay in the knowledge and practice of ventilatory care among nurses in intensive care units in Addis Ababa, Ethiopia. The strategy to address this challenge involved developing comprehensive training programs to improve ventilatory care in critical care settings, emphasizing the continuous education and professional development of healthcare staff.

The study by Itagaki et al. (2020) faced the challenge of understanding the effects of controlled ventilation during intermittent ventilation on diaphragm thickness. A post hoc analysis of an observational study was utilized to examine this relationship. The CASP checklist determined that the study had a clear research question and a well-defined cohort. The observational nature of the study was appropriate for exploring the impact of intermittent ventilation on diaphragm thickness. Data collection methods were adequately described, and appropriate statistical analyses were conducted. The results demonstrated that intermittent ventilation led to respiratory insufficiency due to diaphragm muscle atrophy. The study's findings were significant in understanding the impact of ventilation strategies on diaphragm function, though the observational design limited the ability to establish causality. The strategy derived from this challenge involved closely monitoring diaphragm function and adjusting ventilation strategies to prevent muscle atrophy, thereby ensuring better respiratory outcomes.

Troubleshooting mechanical ventilators presented numerous challenges and required various strategies to ensure effective operation (Mian et al. 2019). The complexity of these devices often overwhelmed medical staff, who needed comprehensive training and regular refreshers to handle the different modes and settings proficiently (Georgiou et al. 2023; Williams and Sharma 2023). Frequent alarms and error codes added to the difficulty, making it challenging to pinpoint the root causes (Silva et al. 2022). Developing a systematic approach to address these alarms, such as prioritizing them based on severity and using flowcharts for common error codes, proved essential (Corey et al. 2020). Patient-ventilator asynchrony also posted significant issues, leading to discomfort and inadequate ventilation (Alqahtani 2021). Close monitoring of patient-ventilator interactions and adjustments to settings like trigger sensitivity and inspiratory time helped mitigate this problem (Rackley 2020).

In a descriptive cross-sectional study by Hassen et al. (2023), knowledge regarding mechanical ventilation and the practice of ventilatory care among nurses working in intensive care units in Addis Ababa, Ethiopia, highlighted significant gaps. Many nurses lacked comprehensive training, which directly impacted their ability to troubleshoot ventilator issues effectively. The study emphasized the importance of regular training and refreshers for medical staff, aligning with the need for systematic approaches to handle complex ventilator settings and alarms.

In congruence to the study of study by Hassen et al. (2023), airway management issues, including blockages, leaks, and improper tube placement, often interfered with ventilation. Regular checks and securing airway devices, ensuring proper humidification, and using appropriate suction techniques addressed these problems effectively (Abrams et al. 2020). Mechanical failures in ventilator components such as valves, sensors, or compressors further complicated matters (Paudel et al. 2021). Routine maintenance, pre-use checks, and having backup ventilators available were crucial strategies to counteract these failures (Martí et al. 2022). Power supply interruptions, due to outages or fluctuations, disrupted ventilator function (Chong et al. 2020). Ensuring a reliable power supply with backup generators and uninterruptible power supplies was vital (Dexter and Clark 2020).

Itagaki et al. (2020) explored the effect of controlled ventilation during assist-control ventilation on diaphragm thickness in a post hoc analysis of an observational study. They found that prolonged mechanical ventilation could lead to diaphragm atrophy, exacerbating patient-ventilator asynchrony issues. Their findings underscored the need for careful monitoring and adjustment of ventilator settings to preserve diaphragm function and improve patient outcomes.

In references to the study of Itagaki et al. (2020), the environmental factors like temperature, humidity, or dust impacted ventilator performance. Maintaining a controlled environment and regularly cleaning and servicing the ventilator prevented these external conditions from affecting its functionality (Martí et al. 2022). Software issues, including bugs or glitches, sometimes caused malfunctions (Chong et al. 2020). Keeping software updated and performing regular diagnostics helped identify and fix these issues promptly (Bezirganoglu et al. 2022). User errors due to incorrect settings or improper use by healthcare staff also presented challenges (Shen et al. 2020). Providing detailed operating manuals, conducting simulation-based training, and implementing a checklist ensured correct usage and minimized these errors (Grasselli et al. 2021).

Comprehensive training of healthcare personnel in ventilator operation, troubleshooting, and emergency protocols played a crucial role in addressing these challenges (Robba et al. 2020). Developing and implementing standard operating procedures for troubleshooting common issues, including step-by-step guides and flowcharts, streamlined the process (Sadat and Arabi 2019). Regular maintenance checks and calibrations ensured optimal functioning of the ventilators (Arabi et al. 2020). Simulation-based training provided practical experience for staff in handling various troubleshooting situations (Al-Omari, Abdelwahed, and Alansari 2021). Access to available technical support from ventilator manufacturers or in-house biomedical engineers ensured quick resolution of issues (Chong et al. 2020; Williams and Sharma 2023). Detailed documentation and reporting of all issues and troubleshooting steps taken helped identify patterns and improve procedures over time (Goodfellow et al. 2024).

A randomized controlled trial by Kacmarek et al. (2020) on neurally adjusted ventilatory assist (NAVA) in acute respiratory failure revealed that using NAVA improved patient-ventilator synchrony and reduced the need for sedation. This study highlighted the importance of advanced ventilatory modes in addressing patient-ventilator asynchrony and optimizing ventilation strategies.

In relevance to the study of Kacmarek et al. (2020), interdisciplinary collaboration between respiratory therapists, nurses, physicians, and biomedical engineers fostered a comprehensive approach to addressing ventilator issues. Continuous monitoring of patient responses to ventilation and adjusting settings as needed, incorporating patient feedback, ensured effective treatment among interdisciplinary collaborations (Peine et al. 2021). Advanced diagnostic tools and software aided in identifying and resolving mechanical ventilator issues quickly and accurately (Maron et al. 2020). Having backup ventilators and emergency protocols in place ensured continuous patient support in case of ventilator failure (Windisch et al. 2020).

5. Conclusion

The challenges in mechanical ventilation included optimizing ventilatory support for patients with acute respiratory failure, addressing significant gaps in the knowledge and practice of ventilatory care among nurses, and understanding the effects of controlled ventilation on diaphragm thickness.

The strategies to tackle these challenges involved integrating advanced ventilatory techniques, developing comprehensive training programs for healthcare professionals, and closely monitoring diaphragm function to adjust ventilation strategies accordingly.

The importance of comprehensive training, interdisciplinary collaboration, and advanced ventilatory techniques ensured optimal patient intensive care by troubleshooting mechanical ventilator.

By addressing these challenges with effective strategies, healthcare providers working in the intensive care units ensures the reliable and safe operation of mechanical ventilators, ultimately improving patient care outcomes.

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