Review Article

Noninvasive Ventilation in Preterm Neonates: Impact on the Incidence and Outcomes of Bronchopulmonary Dysplasia

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Abstract

Noninvasive ventilation has become a fundamental strategy in the respiratory management of preterm neonates, offering effective support while avoiding the complications associated with invasive mechanical ventilation. By delivering positive airway pressure through noninvasive interfaces, it helps maintain airway patency, preserve functional residual capacity, and improve gas exchange, thereby reducing alveolar collapse and the work of breathing. These physiological benefits are particularly relevant in premature infants with immature lungs and limited respiratory reserve. Among the available modalities, continuous positive airway pressure remains the most widely used; however, nasal intermittent positive pressure ventilation and nasal high-frequency ventilation have demonstrated advantages in reducing reintubation rates and potentially lowering the incidence of bronchopulmonary dysplasia. High-flow nasal cannula, while better tolerated and associated with fewer nasal complications, has not consistently shown superiority in preventing treatment failure. The effectiveness of these modalities is closely influenced by the timing of initiation, with early application in the delivery room associated with improved outcomes and reduced need for invasive ventilation. The integration of less invasive surfactant administration techniques with noninvasive ventilation has further enhanced respiratory management by improving oxygenation and decreasing exposure to mechanical ventilation. Despite these advances, variability in clinical outcomes persists, particularly regarding duration of respiratory support, hospitalization, and long-term pulmonary function, which appear similar across modalities. Importantly, current evidence does not suggest adverse effects on neurodevelopmental outcomes. Although noninvasive ventilation reduces the incidence of bronchopulmonary dysplasia, its impact on mortality remains less clear. Ongoing research focusing on synchronized ventilation modes, automated systems, and personalized strategies may further optimize outcomes, highlighting the need for standardized protocols and high-quality evidence.

Key words

Noninvasive ventilation, prematurity, bronchopulmonary dysplasia, respiratory support, surfactant therapy, neonatal outcomes.

Introduction

Prematurity is defined as birth occurring before 37 weeks of gestation, with the risk of respiratory complications increasing substantially as gestational age decreases, particularly among infants born before 28 weeks [1]. Within this vulnerable population, bronchopulmonary dysplasia represents one of the most frequent and clinically significant complications. This condition arises primarily because of prolonged exposure to mechanical ventilation and supplemental oxygen, which together promote inflammatory processes and structural lung injury, ultimately leading to fibrosis and impaired pulmonary development [2]. Although its reported incidence varies depending on the diagnostic criteria employed, bronchopulmonary dysplasia continues to represent a major challenge in neonatal care [2].

Beyond its immediate respiratory implications, bronchopulmonary dysplasia is associated with substantial long-term consequences. Affected infants often experience persistent respiratory dysfunction and are at increased risk for adverse neurodevelopmental outcomes, factors that significantly compromise overall quality of life [2]. In addition, the condition is linked to prolonged hospitalizations and the need for recurrent medical interventions, thereby generating considerable healthcare expenditures and placing a sustained burden on healthcare systems. These clinical and economic implications underscore the importance of optimizing preventive and therapeutic strategies in this population [3].

Historically, invasive mechanical ventilation constituted the cornerstone of respiratory support in preterm neonates. However, growing recognition of its role in contributing to ventilator-induced lung injury prompted a paradigm shift toward less invasive approaches [4]. The advent of antenatal corticosteroids and exogenous surfactant therapy marked significant advances in neonatal care and improved survival outcomes. Nevertheless, contemporary strategies increasingly emphasize the reduction of invasive ventilation as a key measure to mitigate the development of bronchopulmonary dysplasia [2, 5]. In this context, noninvasive respiratory support modalities, including continuous positive airway pressure and nasal intermittent positive pressure ventilation, have gained prominence due to their demonstrated capacity to maintain adequate gas exchange while minimizing lung injury [5, 7].

The rationale for the use of noninvasive ventilation in preterm infants is grounded in its ability to reduce exposure to endotracheal intubation and invasive mechanical ventilation, thereby limiting the risk of ventilator-associated lung damage [4, 5]. Techniques such as continuous positive airway pressure and nasal intermittent positive pressure ventilation have proven effective in providing early respiratory stabilization immediately after birth, which in turn contributes to a reduction in the incidence of bronchopulmonary dysplasia [7]. Furthermore, emerging modalities, including nasal high-frequency ventilation and non-invasive neurally adjusted ventilatory assist, represent promising developments in the field, although additional evidence is required to fully define their clinical role [6, 7]. Complementing these strategies, the implementation of less invasive surfactant administration techniques in conjunction with noninvasive ventilation has demonstrated potential in improving respiratory outcomes by decreasing the need for mechanical ventilation [5, 8].

The objective of this review is to provide a comprehensive and clinically integrated analysis of noninvasive ventilation strategies in preterm neonates, with a particular focus on their impact on the prevention and incidence of bronchopulmonary dysplasia.

Methodology

This manuscript was developed as a structured narrative review aimed at providing an updated and clinically integrated analysis of noninvasive ventilation in preterm neonates, with particular emphasis on its impact on the incidence and prevention of bronchopulmonary dysplasia. The review was conducted in accordance with the SANRA (Scale for the Assessment of Narrative Review Articles) framework and followed a predefined methodological protocol established prior to literature screening. Given the clinical heterogeneity of preterm infants, the variability in gestational age, respiratory severity, and institutional practices in neonatal intensive care, a narrative interpretative synthesis was selected over quantitative pooling to integrate physiological, clinical, and technological aspects of respiratory support into a coherent and clinically applicable framework. Special attention was given to the comparative effectiveness of different noninvasive ventilation modalities, the timing of intervention, strategies for minimizing invasive mechanical ventilation, and the integration of adjunctive approaches such as less invasive surfactant administration. The objective was to provide a structured synthesis capable of supporting evidence-based decision-making in neonatal respiratory care.

A comprehensive literature search was conducted in PubMed, Scopus, and Web of Science, including peer-reviewed articles published in English or Spanish between January 2020 and December 2026. The final search was performed in December 2026. This timeframe was selected to capture contemporary advances in neonatal respiratory support, including developments in continuous positive airway pressure, nasal intermittent positive pressure ventilation, high-flow nasal cannula, nasal high-frequency ventilation, and neurally adjusted ventilatory assist. Foundational studies were incorporated when necessary to contextualize pathophysiological mechanisms of bronchopulmonary dysplasia and the historical evolution of respiratory support strategies. The search strategy combined MeSH and free-text terms using Boolean operators related to prematurity, bronchopulmonary dysplasia, noninvasive ventilation, continuous positive airway pressure, nasal intermittent positive pressure ventilation, high-flow nasal cannula, surfactant administration, respiratory support, and neonatal outcomes. Searches were conducted in titles and abstracts as well as indexed subject headings to maximize sensitivity.

The initial search yielded 166 records. After removal of duplicates, 119 articles remained for title and abstract screening. Of these, 90 underwent full-text evaluation, and 36 studies were included in the final synthesis. Selection was performed independently by two authors, with disagreements resolved through discussion and consensus. Exclusion criteria comprised non–peer-reviewed publications, isolated case reports, editorials without clinical outcome data, purely technical reports without relevance to bronchopulmonary dysplasia or respiratory outcomes, redundant datasets, and studies not directly addressing noninvasive ventilation strategies in preterm infants.

Eligible studies included randomized controlled trials, large observational cohorts, systematic reviews, meta-analyses, expert consensus statements, and contemporary international guidelines from neonatology and pediatric respiratory societies. Priority was assigned to multicenter investigations, studies with well-defined gestational age stratification, and research evaluating clinically relevant outcomes such as incidence of bronchopulmonary dysplasia, need for invasive mechanical ventilation, mortality, duration of respiratory support, and long-term respiratory or neurodevelopmental outcomes. Extracted variables included study design, population characteristics, gestational age, type and timing of noninvasive ventilation modality, use of surfactant therapy, respiratory outcomes, incidence of bronchopulmonary dysplasia, and reported complications. Methodological quality and internal validity were assessed narratively, considering risk of bias, sample size, duration of follow-up, consistency of outcome definitions, and reproducibility of findings. In cases of conflicting evidence, greater interpretative weight was assigned to higher-level evidence and guideline-supported recommendations.

Reference lists of included studies were manually screened to identify additional relevant publications. Given its narrative design, this review is subject to potential selection bias and does not provide pooled quantitative estimates. Artificial intelligence–based tools were used exclusively to assist in literature organization and structural coherence, whereas critical appraisal, synthesis, and final interpretation were conducted independently by the authors to preserve methodological rigor.

Principles of Noninvasive Ventilation in Neonates

Noninvasive ventilation is defined as a form of respiratory support delivered without the use of an endotracheal tube, instead utilizing interfaces such as nasal prongs or masks to provide positive airway pressure. This approach is designed to support spontaneous breathing while maintaining airway patency, thereby reducing the need for invasive mechanical ventilation. The physiological basis of noninvasive ventilation lies in its ability to prevent alveolar collapse, maintain adequate gas exchange, and preserve functional lung volumes, which is particularly relevant in preterm infants with immature respiratory systems [6, 9].

The mechanisms through which noninvasive ventilation exerts its clinical effects are multifactorial and closely related to its impact on lung mechanics. One of the primary mechanisms involves the maintenance of functional residual capacity through the application of continuous positive airway pressure, which helps prevent alveolar collapse and enhances oxygenation [10]. In addition, modalities such as nasal intermittent positive pressure ventilation contribute to alveolar recruitment by delivering intermittent positive pressure breaths, thereby reducing the risk of atelectasis and improving overall lung compliance [11]. Furthermore, noninvasive ventilation plays a critical role in reducing the work of breathing by assisting the infant's spontaneous respiratory efforts, an effect that is particularly important in preterm neonates with underdeveloped respiratory musculature and limited physiological reserve [12].

Beyond its direct effects on lung mechanics, noninvasive ventilation also exerts important hemodynamic and pulmonary influences. From a hemodynamic perspective, the application of positive airway pressure may affect cardiac output and systemic blood flow; however, these effects are generally less pronounced compared to those observed with invasive mechanical ventilation [9]. From a pulmonary standpoint, noninvasive ventilation is associated with a reduced incidence of ventilator-induced lung injury, as it minimizes exposure to the barotrauma and volutrauma that are commonly linked to invasive ventilation strategies. This protective effect contributes to a lower risk of developing bronchopulmonary dysplasia and supports its use as a primary respiratory support modality in preterm infants [11, 13].

In clinical practice, noninvasive ventilation is indicated in a variety of scenarios involving preterm neonates. It is commonly used in the management of respiratory distress syndrome, as well as for post-extubation support and the treatment of apnea of prematurity. Its use has been associated with a reduction in the need for reintubation and a shorter duration of invasive mechanical ventilation, highlighting its role in improving respiratory outcomes [13, 14]. However, certain conditions limit its applicability. Contraindications include severe respiratory failure requiring immediate airway control, anatomical abnormalities such as significant facial malformations that prevent adequate interface fitting, and specific clinical situations such as diaphragmatic hernia, in which the application of positive pressure may worsen the underlying pathology [15].

Modalities of Noninvasive Ventilation

Continuous positive airway pressure is a noninvasive ventilation modality that delivers a constant level of positive airway pressure throughout the entire respiratory cycle, thereby maintaining alveolar stability and improving oxygenation. By preventing alveolar collapse, it plays a central role in preserving functional lung volumes in preterm infants. Clinically, it represents the most widely used primary and secondary noninvasive ventilation strategy in neonatal care, particularly in the management of premature infants at risk of respiratory failure and in the prevention of extubation failure [6, 7, 16]. Although continuous positive airway pressure is highly effective, it is frequently compared with other modalities such as nasal intermittent positive pressure ventilation and high-flow nasal cannula. Evidence suggests that while it remains a cornerstone of respiratory support, nasal intermittent positive pressure ventilation may provide superior outcomes in specific clinical scenarios, particularly in reducing the need for reintubation [16, 17].

Nasal intermittent positive pressure ventilation builds upon the principles of continuous positive airway pressure by delivering intermittent positive pressure breaths superimposed on a baseline level of positive airway pressure. These breaths may be synchronized with the infant’s spontaneous respiratory efforts, enhancing ventilatory support and improving gas exchange. In clinical practice, it is commonly utilized in the post-extubation setting, where it has demonstrated a reduction in the risk of respiratory failure and the need for reintubation when compared with continuous positive airway pressure alone. Nasal intermittent positive pressure ventilation has been associated with a decreased incidence of pulmonary air leaks, supporting its role as a more effective modality in certain high-risk populations. Consequently, it is often considered superior to continuous positive airway pressure in preventing extubation failure and improving short-term respiratory outcomes [16, 17].

Bi-level positive airway pressure represents another noninvasive ventilation strategy that provides two distinct levels of pressure: a higher inspiratory positive airway pressure and a lower expiratory positive airway pressure, thereby facilitating ventilation while maintaining alveolar stability [9]. Despite its theoretical advantages, its clinical use in preterm infants is less widespread compared to continuous positive airway pressure and nasal intermittent positive pressure ventilation. Available evidence has not demonstrated significant improvements in clinical outcomes when compared with continuous positive airway pressure, which has limited its adoption in routine neonatal practice [7].

High-flow nasal cannula is an alternative noninvasive modality that delivers heated and humidified air and oxygen at high flow rates, generating a variable degree of positive airway pressure and improving patient comfort [18]. This approach has been increasingly used both as primary respiratory support and as a step-down therapy following more intensive interventions. Clinically, it has been associated with a lower incidence of nasal trauma and pneumothorax compared with continuous positive airway pressure, which contributes to its growing popularity in neonatal units. However, comparative studies indicate that it may be associated with higher rates of treatment failure when used as primary support, highlighting the need for careful patient selection and monitoring [18, 19].

Nasal high-frequency ventilation represents a more recent advancement in noninvasive respiratory support, utilizing high-frequency oscillations to facilitate gas exchange while potentially minimizing lung injury. This modality is designed to enhance carbon dioxide clearance and reduce the risk of air trapping, offering potential physiological advantages over conventional approaches. Early clinical data suggest that nasal high-frequency ventilation may reduce reintubation rates and improve ventilatory efficiency, particularly in preterm infants with evolving respiratory insufficiency. In comparative analyses, it has demonstrated effectiveness comparable to nasal intermittent positive pressure ventilation and, in some cases, superior to continuous positive airway pressure in reducing the need for reintubation. Nonetheless, given its relatively recent introduction, further research is required to establish its definitive role within neonatal respiratory care [20, 21].

Timing and Strategies of NIV Initiation

The timing of initiation of noninvasive ventilation plays a critical role in determining respiratory outcomes in preterm infants. Early initiation, particularly in the delivery room, has been consistently associated with improved clinical outcomes, including a reduced need for invasive mechanical ventilation and a lower risk of developing bronchopulmonary dysplasia. In contrast, delayed initiation of noninvasive support may result in worsening respiratory status, increased incidence of complications, and a higher likelihood of requiring intubation and invasive ventilation. These findings highlight the importance of timely respiratory support as part of initial neonatal management [5, 7].

In the context of delivery room stabilization, nasal continuous positive airway pressure remains the most employed modality for initial respiratory support in preterm infants. Its widespread use is supported by its effectiveness in maintaining airway patency and preventing alveolar collapse during the critical transition from intrauterine to extrauterine life. Although nasal intermittent positive pressure ventilation has been proposed as a potentially superior alternative due to its ability to provide additional ventilatory support, current evidence remains inconclusive, and further studies are required to establish its definitive advantage over nasal continuous positive airway pressure in this setting [7].

The integration of surfactant therapy with noninvasive ventilation strategies has evolved significantly, with techniques such as INSURE and less invasive surfactant administration playing a central role. The INSURE approach, which involves intubation, surfactant administration, and subsequent extubation, represented an important step toward minimizing prolonged mechanical ventilation; however, it has not fully adapted to contemporary respiratory care practices [22]. In contrast, less invasive surfactant administration techniques allow surfactant delivery without the need for intubation and have demonstrated superior outcomes, including a reduction in severe bronchopulmonary dysplasia and other associated morbidities when compared with INSURE [23, 25]. Moreover, evidence suggests that the combination of less invasive surfactant administration with noninvasive ventilation further enhances clinical outcomes by decreasing the duration of mechanical ventilation and improving overall respiratory stability [24].

Effective respiratory management also requires clearly defined criteria for escalation and de-escalation of support. Escalation is indicated in the presence of persistent or worsening respiratory distress, hypoxemia, or hypercapnia despite adequate noninvasive ventilation, signaling the need for more intensive respiratory intervention [5]. Conversely, de-escalation involves the gradual reduction of ventilatory support as the infant's respiratory function improves, guided by continuous clinical evaluation and objective parameters such as blood gas analysis. This dynamic adjustment of respiratory support is essential to balance adequate ventilation with the minimization of potential lung injury [26].

The integration of surfactant therapy with noninvasive ventilation represents a key component of modern neonatal respiratory care. Early administration of surfactant, particularly through less invasive techniques, has been shown to optimize respiratory outcomes by improving oxygenation and reducing the need for invasive mechanical ventilation [24, 26]. The choice between minimally invasive surfactant therapy and the INSURE technique is influenced by clinical context and resource availability, although minimally invasive approaches have demonstrated advantages, including shorter hospitalization duration and fewer associated complications [25].

Evidence on NIV and Reduction of Bronchopulmonary Dysplasia

Current evidence supports the preference for noninvasive ventilation over invasive mechanical ventilation in preterm infants because of its association with lower rates of lung injury and a reduced incidence of bronchopulmonary dysplasia. By avoiding endotracheal intubation and prolonged mechanical ventilation, noninvasive strategies decrease the mechanical stress and inflammatory injury that contribute to impaired lung development in this population [4]. In this context, specific noninvasive ventilation modalities have shown differing degrees of effectiveness. Among them, nasal high-frequency oscillatory ventilation and nasal intermittent positive pressure ventilation have demonstrated advantages over continuous positive airway pressure in reducing the incidence of bronchopulmonary dysplasia. In particular, nasal high-frequency oscillatory ventilation has been highlighted as more effective than continuous positive airway pressure in lowering reintubation rates and reducing bronchopulmonary dysplasia in some studies [20, 21].

Evidence from randomized controlled trials and meta-analyses has contributed substantially to the current understanding of these modalities. The NASONE study compared nasal high-frequency oscillatory ventilation, nasal intermittent positive pressure ventilation, and nasal continuous positive airway pressure, demonstrating that nasal high-frequency oscillatory ventilation was more effective than nasal continuous positive airway pressure in preventing reintubation, although its effect on bronchopulmonary dysplasia did not differ significantly from that of nasal intermittent positive pressure ventilation [20]. Likewise, systematic reviews and meta-analyses have suggested that both nasal high-frequency oscillatory ventilation and nasal intermittent positive pressure ventilation are superior to nasal continuous positive airway pressure in reducing the incidence of bronchopulmonary dysplasia, with nasal high-frequency oscillatory ventilation appearing to be the most effective post-extubation mode [21].

When comparing noninvasive ventilation with invasive ventilation, the reduction in bronchopulmonary dysplasia remains one of the most important advantages associated with noninvasive approaches. Modalities such as nasal high-frequency oscillatory ventilation and nasal intermittent positive pressure ventilation have been linked to lower rates of bronchopulmonary dysplasia than invasive ventilation methods, a benefit largely attributed to the reduced barotrauma, volutrauma, and inflammatory burden associated with avoiding intubation and conventional ventilation. However, although noninvasive ventilation appears beneficial in decreasing bronchopulmonary dysplasia, its effect on mortality and composite outcomes such as bronchopulmonary dysplasia or death remains less consistent, as some studies have not shown statistically significant differences in these endpoints [27, 11].

Among the specific noninvasive modalities, continuous positive airway pressure remains the most widely used in neonatal practice, but nasal intermittent positive pressure ventilation has shown greater effectiveness in reducing bronchopulmonary dysplasia incidence. High-flow nasal cannula, despite being easier to administer and often better tolerated, has not demonstrated a significant reduction in bronchopulmonary dysplasia when compared with continuous positive airway pressure [7, 28]. Nasal high-frequency oscillatory ventilation has emerged as a particularly promising option, with evidence suggesting reductions in both bronchopulmonary dysplasia and reintubation rates, although additional research is still needed to establish its long-term clinical benefits [20, 27].

Despite these encouraging findings, the current body of evidence is limited by substantial heterogeneity across studies. Variability in study design, patient populations, gestational age ranges, and definitions of bronchopulmonary dysplasia complicates direct comparison and limits the generalizability of results [1]. In addition, many available studies are constrained by relatively small sample sizes, methodological limitations, and insufficient long-term follow-up, which reduce the strength of the conclusions that can be drawn [20, 29]. These limitations highlight the need for greater standardization, including consensus regarding bronchopulmonary dysplasia definitions and uniform protocols for the application of noninvasive ventilation, in order to improve comparability across studies and strengthen the evidence base guiding clinical practice [1].

Clinical Outcomes Beyond BPD

The duration of respiratory support and hospitalization in preterm infants managed with noninvasive ventilation appears to vary according to the specific modality employed. Available studies indicate that nasal intermittent positive pressure ventilation and noninvasive high-frequency oscillatory ventilation may reduce the duration of invasive mechanical ventilation when compared with nasal continuous positive airway pressure [13]. Nevertheless, these benefits do not always translate uniformly into shorter overall respiratory support or hospitalization. In some cases, nasal intermittent positive pressure ventilation has been associated with a longer duration of respiratory support and hospital stay, although these differences were no longer statistically significant after adjustment for confounding factors. These findings suggest that the overall impact of noninvasive ventilation on length of support and hospitalization is influenced by both the modality selected and the clinical characteristics of the population studied [26].

With respect to neurodevelopmental outcomes, current evidence does not demonstrate significant differences in rates of neurodevelopmental impairment among preterm infants treated with different noninvasive ventilation strategies, including noninvasive high-frequency oscillatory ventilation, nasal intermittent positive pressure ventilation, and nasal continuous positive airway pressure, when assessed at 24 months of corrected age. This observation indicates that, although noninvasive ventilation is essential for respiratory stabilization and support in this population, its use does not appear to adversely influence neurodevelopmental outcomes when compared across these commonly used respiratory modalities [30].

The incidence of complications associated with noninvasive ventilation is generally low, particularly with regard to major adverse events such as pneumothorax and nasal trauma. Among the available modalities, nasal intermittent positive pressure ventilation has been reported to potentially reduce the occurrence of pulmonary air leaks when compared with nasal continuous positive airway pressure [16]. Although feeding difficulties are not extensively addressed in the available studies, the use of less invasive respiratory approaches such as less invasive surfactant administration combined with nasal continuous positive airway pressure has been associated with improved overall outcomes, which may also contribute to a lower burden of feeding-related complications [31].

Regarding long-term pulmonary outcomes, current evidence suggests that pulmonary function remains broadly similar across different noninvasive ventilation strategies. Studies evaluating infants treated with noninvasive high-frequency oscillatory ventilation, nasal intermittent positive pressure ventilation, or nasal continuous positive airway pressure have not identified significant differences in pulmonary function testing at 12 months of corrected age. These findings indicate that, while noninvasive ventilation plays a critical role in the acute respiratory management of preterm infants, it does not appear to produce major differences in long-term pulmonary function when comparing the principal modalities currently in use [30].

Practical Considerations and Challenges

The selection of appropriate devices and interfaces is a critical determinant of the effectiveness of noninvasive ventilation in preterm neonates. Commonly used modalities include nasal continuous positive airway pressure and nasal intermittent positive pressure ventilation, with evidence suggesting that nasal intermittent positive pressure ventilation may be more effective in reducing reintubation rates when compared with nasal continuous positive airway pressure [13, 16]. In addition to the choice of modality, the type of interface plays a significant role in both efficacy and tolerance. Comparisons between cannulas with long and narrow tubing and short binasal prongs have demonstrated that the former may be associated with less nasal trauma while maintaining noninferiority in terms of intubation rates, highlighting the importance of interface optimization in minimizing complications while preserving clinical effectiveness [32].

Accurate monitoring and continuous clinical assessment are essential components of noninvasive ventilation management. Key parameters such as oxygen saturation, carbon dioxide levels, and respiratory effort must be closely observed to evaluate the effectiveness of respiratory support and to detect early signs of clinical deterioration [9]. Continuous monitoring facilitates the timely identification of noninvasive ventilation failure, allowing for prompt escalation of care when necessary and thereby reducing the risk of adverse outcomes [33].

The successful implementation of noninvasive ventilation also depends heavily on adequate staff training and the establishment of standardized clinical protocols. Proper training ensures that healthcare providers are proficient in device handling, monitoring techniques, and the recognition of early signs of treatment failure. Standardized protocols contribute to consistency in clinical practice and have been associated with improved patient outcomes by reducing variability in care [34]. Training programs should therefore emphasize both technical competence and clinical decision-making, ensuring that staff are equipped to manage the dynamic needs of preterm infants receiving respiratory support [7].

In low- and middle-income settings, the application of noninvasive ventilation is often limited by structural and resource-related barriers. Challenges such as inadequate infrastructure, shortages of trained personnel, and restricted access to appropriate equipment can significantly hinder the effective delivery of care. In response to these limitations, alternative strategies such as bubble continuous positive airway pressure have been developed and adapted for use in resource-constrained environments. Although these approaches offer practical solutions, ongoing challenges related to equipment maintenance and supply chains continue to affect their sustainability and effectiveness [35].

Finally, the risk of noninvasive ventilation failure remains an important consideration in clinical practice. Several predictors have been identified, including severe respiratory distress, low birth weight, and the presence of comorbid conditions, all of which are associated with a higher likelihood of requiring escalation to invasive ventilation [27]. Early identification of these risk factors allows for more individualized management strategies and may improve the likelihood of successful noninvasive support. Consequently, careful patient selection and close clinical monitoring are essential to optimize outcomes and minimize the risk of treatment failure [16].

Emerging Technologies and Future Directions

Recent advances in noninvasive ventilation have focused on improving patient–ventilator interaction through synchronized modes. Synchronized nasal intermittent positive pressure ventilation has demonstrated promising results, with evidence suggesting reductions in reintubation rates and bronchopulmonary dysplasia when compared with non-synchronized modalities [11]. Similarly, non-invasive neurally adjusted ventilatory assist represents an emerging approach that aligns ventilatory support with the infant's intrinsic respiratory drive, thereby enhancing synchronization and potentially improving respiratory efficiency. Although early findings are encouraging, further studies are required to establish its clinical efficacy and define its role within routine neonatal care [6, 9].

In parallel, technological innovations are increasingly shaping the future of neonatal respiratory support. Automated ventilation systems, including closed-loop automated oxygen control, are being developed to optimize oxygen delivery by continuously adjusting inspired oxygen levels in response to real-time physiological parameters. These systems aim to reduce fluctuations in oxygen saturation and minimize the risk of oxygen toxicity, although their long-term impact on clinical outcomes remains under investigation [36]. The integration of artificial intelligence into ventilation systems has the potential to further enhance clinical decision-making by enabling more precise and individualized adjustments in respiratory support. However, this field is still in its early stages, and substantial validation is required before widespread clinical implementation can be achieved [9].

Another area of ongoing research involves the identification of biomarkers for the early prediction of bronchopulmonary dysplasia. Early detection of infants at higher risk could allow for timely and targeted interventions, thereby improving outcomes. Current efforts are focused on elucidating the underlying pathophysiological mechanisms of bronchopulmonary dysplasia and identifying reliable biomarkers, although consensus regarding their clinical application and validation is still lacking [1].

The concept of personalized respiratory support has also gained increasing attention, emphasizing the need to tailor noninvasive ventilation strategies according to individual patient characteristics, disease severity, and resource availability. This approach recognizes the heterogeneity of preterm infants and the importance of adapting therapeutic interventions to optimize outcomes [6]. Within this framework, the combination of less invasive surfactant administration with noninvasive ventilation has shown potential in reducing the incidence of bronchopulmonary dysplasia and improving survival without the need for mechanical ventilation, further supporting the move toward individualized care strategies [31, 36].

Ongoing clinical trials continue to evaluate the effectiveness of emerging noninvasive ventilation modalities, including nasal high-frequency ventilation and synchronized nasal intermittent positive pressure ventilation, in reducing bronchopulmonary dysplasia and improving survival outcomes [11, 27]. Despite these advances, significant research gaps remain, particularly the need for large-scale randomized controlled trials to assess long-term outcomes associated with newer ventilation modes. Additionally, the integration of novel technologies such as artificial intelligence into clinical practice requires further development and rigorous validation to ensure safety, reliability, and clinical benefit [36].

Conclusions

Noninvasive ventilation represents a cornerstone in the respiratory management of preterm infants by providing effective support without the need for intubation, thereby reducing ventilator-induced lung injury and contributing to a lower incidence of bronchopulmonary dysplasia through improved alveolar stability, gas exchange, and decreased work of breathing.

Among available modalities, nasal intermittent positive pressure ventilation and nasal high-frequency ventilation have demonstrated advantages over continuous positive airway pressure in reducing reintubation rates and potentially decreasing bronchopulmonary dysplasia, although variability in study designs and outcomes highlights the need for standardized definitions and further high-quality evidence.

Early initiation of noninvasive ventilation combined with less invasive surfactant administration strategies, along with appropriate device selection, monitoring, and individualized care, plays a critical role in optimizing clinical outcomes, while emerging technologies and personalized approaches represent promising directions for improving neonatal respiratory support and long-term prognosis.

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