Mechanical Ventilation And Beyond: A Comprehensive Review Of Nursing Roles In Weaning Protocols And Respiratory Therapy

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Abstract

Background
Mechanical ventilation is a cornerstone of intensive care for critically ill patients, yet prolonged use increases risks of complications like ventilator-associated pneumonia and ICU length of stay. Nurse-led weaning protocols have emerged as evidence-based strategies to shorten ventilation duration and improve outcomes, shifting from physician-driven to integrated, multiprofessional models.

Methods
This comprehensive review synthesizes evidence from randomized controlled trials, quasi-experimental studies, observational cohorts, qualitative research, and concept analyses on nursing roles in weaning protocols and respiratory therapy. A conceptual framework maps nursing contributions across stabilization, active weaning, and post-extubation recovery.

Results
Nurse-led protocols reduced mechanical ventilation duration by 1-2 days, ICU stays, and ventilator-associated events compared to physician-led care. Key predictors like Rapid Shallow Breathing Index (RSBI <105) and tools such as Burns Wean Assessment Program enhanced weaning success, with nurses pivotal in monitoring, SBTs, and complication prevention across diverse populations.

Conclusions
Empowering nurses through standardized protocols optimizes weaning, reduces burdens, and extends care

to long-term recovery. Future efforts should address implementation barriers, AI integration, and global standardization to leverage nursing autonomy fully.

Keywords Mechanical ventilation, Nurse-led weaning, Weaning protocols, Respiratory therapy, Spontaneous breathing trials, Ventilator-associated pneumonia

Introduction

Mechanical ventilation has become a cornerstone of modern intensive care, but its expanding use has generated a complex clinical, organizational, and economic burden that directly foregrounds the central role of nurses in weaning and respiratory therapy across the continuum of critical illness. Historically, ventilator discontinuation was physician-driven and episodic, yet accumulating evidence demonstrates that protocolized and nurse-led weaning models can shorten ventilation duration, ICU length of stay, and related complications, prompting a paradigm shift from viewing weaning as a discrete terminal event to understanding it as an integrated, multiprofessional process in which critical care nurses function as continuous decision-makers at the bedside. Within this evolving landscape, the concept of "Mechanical Ventilation and Beyond" underscores how nursing practice now spans not only ventilator liberation but also prevention of ventilator-associated harm, optimization of patient–ventilator interaction, and long-term functional and psychosocial recovery, highlighting the need to systematically synthesize nurse-centric evidence to guide practice, education, and policy (Hirzallah et al., 2019).

Globally, invasive mechanical ventilation (IMV) is required for most critically ill adults admitted to intensive care units, with estimates suggesting that more than 90% of ICU patients will need ventilatory support at some point during their stay, reflecting rising burdens of sepsis, acute respiratory distress syndrome (ARDS), multi-organ failure, and complex surgical and oncologic interventions. Prolonged IMV is strongly associated with ventilator-associated pneumonia (VAP), ventilator-induced lung injury, delirium, neuromuscular weakness, and extended ICU and hospital length of stay, all of which contribute to increased mortality, long-term disability, and substantial resource consumption, making efficient and safe weaning a major determinant of both individual prognosis and health-system sustainability. The COVID-19 pandemic dramatically amplified these trends by exposing limitations in ICU capacity, workforce shortages, and variability in weaning practices across institutions and regions, thereby intensifying interest in scalable, protocolized strategies to mitigate the global burden of prolonged ventilation while preserving quality and safety of care (Akella et al., 2022).

Early intensive care practice conceptualized mechanical ventilation as a highly specialized, physician-controlled intervention, with decisions about weaning and extubation largely based on intermittent physician assessments and non-standardized criteria that often-delayed liberation despite physiologic readiness. As evidence accumulated that protocol-directed weaning could substantially reduce the duration of mechanical ventilation and ICU stay, multidisciplinary teams began to experiment with delegating weaning initiation and titration to non-physician clinicians under carefully designed protocols. Within this context, critical care nurses emerged as pivotal agents for protocolized weaning because of their continuous bedside presence, familiarity with ventilator settings and patient trajectories, and expertise in titrating sedation, mobilizing patients, and detecting subtle signs of distress, leading randomized and quasi-experimental studies to test nurse-led weaning protocols against usual physician-led care and demonstrate meaningful reductions in ventilation time, ICU length of stay, and sometimes VAP incidence. Over the last decade, this evidence has matured into a broader movement toward nurse-driven or nurse–respiratory therapist–driven ventilator liberation bundles, though implementation remains heterogeneous due to regulatory, cultural, and organizational barriers and persistent uncertainty about the generalizability of existing trials across diverse ICU contexts (Wang et al., 2025).

The proposed conceptual framework of "Mechanical Ventilation and Beyond" positions nursing roles in weaning not as a discrete technical task but as a longitudinal, patient-centered process encompassing three interconnected domains: stabilization on the ventilator, active weaning and liberation, and post-extubation respiratory recovery and rehabilitation. In the stabilization domain, critical care nurses coordinate ventilator settings, sedation and analgesia, positioning, secretion management, and early mobilization to prevent secondary lung injury and deconditioning, thereby creating the physiologic conditions necessary for future weaning success. In the active weaning domain, nurses apply protocolized readiness screening, conduct or supervise spontaneous breathing trials, adjust ventilator support in collaboration with respiratory therapists and physicians, and address non-respiratory barriers such as pain, delirium, anxiety, and hemodynamic instability, integrating continuous clinical judgment with explicit evidence-based criteria. Beyond extubation, nurses maintain a central role in monitoring for respiratory fatigue, airway compromise, and aspiration risk, implementing noninvasive respiratory support and physiotherapy as needed, and supporting communication, sleep, and psychological adaptation, thus extending the scope of ventilator weaning into a broader trajectory of survivorship and functional recovery. This framework emphasizes that nurse-led weaning should be conceptualized not only as task-shifting from physicians but as a systems-level redesign of ICU care that integrates protocols, interprofessional collaboration, patient engagement, and outcome-oriented quality metrics across the entire ventilation continuum (Wang et al., 2025).

Despite growing recognition that nurse-led and nurse-driven weaning protocols can reduce duration of mechanical ventilation and ICU length of stay, the evidence base remains constrained by moderate-to-low methodological quality, limited sample sizes, and a predominance of single-center studies, raising questions about external validity across different ICU types, case-mix profiles, staffing models, and health systems. Furthermore, recent systematic reviews have highlighted substantial heterogeneity in the content, intensity, and implementation strategies of nurse-led protocols, with variations in readiness criteria, frequency of assessment, decision thresholds, and roles of respiratory therapists and physicians, making it difficult to attribute observed benefits to specific nursing actions or to define best standardized practices. Critically, most existing trials and reviews focus primarily on biomedical endpoints such as ventilation days, ICU and hospital length of stay, VAP rates, and mortality, while underreporting or omitting nursing-sensitive outcomes including patient comfort, dyspnea and anxiety relief, communication, family engagement, and long-term quality of life all domains in which nurses are uniquely positioned to influence “beyond-the-ventilator” recovery. There is also a notable gap in theoretical and conceptual work explicitly linking advanced nursing competencies, such as clinical reasoning, ethical decision-making, and advocacy, to ventilator weaning processes and outcomes, with only a few recent concept analyses and qualitative studies describing nurse–patient interaction and nurse consciousness in mechanically ventilated care. Addressing these gaps by systematically reviewing nurse-centric models, integrating quantitative and qualitative evidence, and situating findings within an explicit conceptual framework can inform more robust protocol design, tailored implementation strategies, and policy recommendations that fully leverage nursing capabilities in respiratory therapy and ventilator liberation (Ghiasvand et al., 2023).

The overarching objective of this review is to synthesize contemporary evidence on nursing roles in mechanical ventilation weaning and respiratory therapy, with specific aims to (1) describe the global burden and epidemiology of mechanical ventilation and its implications for nursing workload and competencies; (2) trace the historical evolution from physician-led to protocolized and nurse-led weaning models; (3) map and critique existing nurse-centric weaning and respiratory care protocols; and (4) integrate findings into the “Mechanical Ventilation and Beyond” framework to articulate a comprehensive, practice-oriented model of nursing contribution across the ventilation trajectory. By systematically collating data from randomized controlled trials, quasi-experimental studies, observational cohorts, qualitative research, and concept analyses, this review is expected to clarify the magnitude and consistency of effects of nurse-led and nurse-driven weaning approaches on key outcomes such as duration of mechanical ventilation, ICU and hospital length of stay, VAP incidence, extubation success, and mortality, while also highlighting underexplored nursing-sensitive and patient-centered outcomes relevant to long-term recovery and quality of life. A further anticipated contribution is the identification of contextual and implementation factors that facilitate or hinder successful adoption of nurse-led weaning protocols, thereby providing actionable insights for clinicians, educators, and policymakers seeking to optimize ventilator liberation practices and advance the professional scope and autonomy of critical care nurses. By explicitly anchoring these findings within a conceptual model that extends "beyond" the ventilator, the review aims to guide future research agendas, inform competency frameworks and curricula, and support the development of standardized quality indicators that recognize and measure the full spectrum of nursing contributions to respiratory therapy and mechanical ventilation outcomes (Moussanang et al., 2025).

Physiological and Technical Foundations

Mechanical ventilation serves as a cornerstone intervention for patients experiencing respiratory failure, where nurses play a pivotal role in recognizing indications, optimizing settings, ensuring synchrony, assessing weaning readiness, and mitigating complications to facilitate successful liberation from ventilatory support. This section delineates the foundational physiological mechanisms and technical aspects underpinning nursing management in weaning protocols and respiratory therapy, emphasizing evidence-based practices that enhance patient outcomes in critical care environments (Pearson et al., 2022).

Respiratory failure manifests through intricate pathophysiological mechanisms disrupting gas exchange, categorized primarily into Type 1 (hypoxemic) failure due to ventilation-perfusion mismatches, shunt, diffusion impairments, or alveolar hypoventilation from conditions like pneumonia, acute respiratory distress syndrome (ARDS), or pulmonary edema, and Type 2 (hypercapnic) failure arising from ventilatory pump inadequacy, impaired neural drive as in drug overdoses or neuromuscular diseases, increased dead space, or respiratory muscle fatigue leading to CO_2 retention. These mechanisms trigger compensatory responses such as tachypnea, increased work of breathing, and eventual decompensation, necessitating mechanical ventilation (MV) indications including refractory hypoxemia (PaO_2 <60 mmHg despite high FiO_2), acute hypercapnic respiratory acidosis (pH <7.25), respiratory muscle fatigue evidenced by paradoxical breathing, shock with metabolic acidosis requiring ventilatory support, and airway protection failure from altered mental status or obstruction, where nurses initiate rapid assessment using arterial blood gases, clinical signs like use of accessory muscles, and vital signs to prompt timely intubation and ventilation. In nursing practice, early identification through continuous monitoring prevents progression to arrest, with protocolized responses aligning MV initiation to improve oxygenation, reduce work of breathing, and support hemodynamic stability, particularly in ICU settings where multidisciplinary teams rely on nursing vigilance for optimal outcomes (Pearson et al., 2022).

Volume-controlled (VC) ventilation delivers a preset tidal volume (typically 6-8 mL/kg ideal body weight) with pressure varying based on lung compliance and resistance, ideal for patients with stable mechanics but risking barotrauma if high plateau pressures exceed 30 cmH_2O, while pressure-controlled (PC) ventilation limits inspiratory pressure to a set level (often 15-25 cmH_2O) allowing variable tidal volumes suited for ARDS to minimize volutrauma, with nurses adjusting flow rates, inspiratory times, and PEEP (5-15 cmH_2O) to balance oxygenation and CO_2 clearance. Synchronized intermittent mandatory ventilation (SIMV) combines mandatory breaths with spontaneous efforts supported by pressure support (PSV, 5-20 cmH_2O), promoting patient effort during weaning by synchronizing mandatory breaths to neural timing, reducing atrophy risk compared to fully controlled modes, whereas pure PSV augments all spontaneous breaths without backup rate, facilitating progressive respiratory muscle conditioning through adjustable PS levels titrated to respiratory rate <25-30 bpm and tidal volumes 6-8 mL/kg. Nurses tailor initial settings via waveform analysis and ABGs, transitioning modes based on patient response, with evidence supporting SIMV+PSV hybrids like AutoFlow for lower peak pressures and enhanced synchrony in weaning protocols (Wu et al., 2023).

Patient-ventilator synchrony hinges on precise alignment of ventilator cycling with neural respiratory drive, disrupted by asynchronies like ineffective triggering (high sensitivity thresholds >-2 cmH_2O needed), double triggering (short inspiratory time), auto-triggering (circuit leaks), or delayed termination (insensitive flow cycling 25-50% peak flow), which elevate work of breathing, prolong MV duration, and precipitate diaphragm fatigue, with nurses detecting these via pressure/time, flow/time, and volume/time waveforms showing scooped pressure dips or flow oscillations. Key monitoring parameters include peak/plateau pressures (<30/35 cmH2O), driving pressure (<15 cmH2O), auto-PEEP (expiratory hold), esophageal pressure for transpulmonary dynamics, and asynchrony index (AI <10% target), where nurses perform hourly ventilator checks, adjust rise times (100-200 ms), and use advanced modes like neurally adjusted ventilatory assist (NAVA) for proportional support, significantly reducing PVA incidence from 25-80% baseline. In practice, training empowers nurses to interpret loops (phase lag in PV loops) and trends (RR, MV mismatches), intervening with sedation optimization, cuff pressure management (20-30 cmH2O), and protocolized adjustments to foster comfort, shorter ICU stays, and weaning success (Navalesi, 2011).

Weaning pathophysiology involves reversing ventilator-induced diaphragm dysfunction, residual sedation effects, and cardiopulmonary interactions where abrupt liberation spikes respiratory load via increased dead space, elastic recoil demands, and auto-PEEP in COPD, necessitating gradual load reduction to rebuild endurance and strength. Readiness criteria encompass clinical stability (RR <30 bpm, FiO2 ≤0.4, PEEP ≤5-8 cmH2O), hemodynamic adequacy (no/high-dose vasopressors), oxygenation (PaO2/FiO2 >150-200), and objective indices: Rapid Shallow Breathing Index (RSBI = f/VT ≤105 breaths/min/L) measured during 1-2 min spontaneous breathing trial (SBT) on CPAP/PS 5 cmH2O, predicting extubation success with 94.8% sensitivity, while Compliance, Rate, Oxygenation, Pressure (CROP) index ([Crs × MIP × (PaO2/PAO2)] / RR >13) integrates multiparametric assessment though less favored for complexity. Nurses lead daily SBT screens within protocols, documenting RSBI trends, integrating CROP for high-risk cases, and advancing via PS reduction (8→5→0 cmH2O) or T-piece, with evidence affirming nurse-driven approaches shorten MV by 1-2 days via timely assessments (Gaddam et al., 2025).

Prolonged ventilation (>48 hours) precipitates ventilator-associated pneumonia (VAP, incidence 18-20%), driven by microaspiration, biofilm formation, and impaired clearance, with early-onset (<96h) linked to community pathogens and late-onset to multidrug-resistant organisms, increasing mortality 20-40% and MV duration; barotrauma (2-5%) from overdistension causing pneumothorax or pneumomediastinum when plateau >30 cmH2O, and delirium (60-80% ICU patients) exacerbating asynchrony, self-extubation, and prolonged LOS via inflammation, sedatives, and immobility. Nurses mitigate VAP via bundles (head elevation 30-45°, oral care chlorhexidine, subglottic suction, VAPET scores), barotrauma through low tidal volumes and Pplat monitoring, and delirium with CAM-ICU screening, ABCDEF bundles (assess pain/sedation, delirium monitoring, early mobility), reducing incidence by 30-50% and associated MV extension. These interventions underscore nursing centrality in surveillance, bundle adherence, and multidisciplinary weaning to avert 14-day MV thresholds heightening complications (Khan et al., 2022).

Nursing Roles in Mechanical Ventilation

Nursing roles in mechanical ventilation encompass a multifaceted approach where nurses serve as the frontline caregivers, integrating vigilant monitoring, technical proficiency, and holistic patient support to optimize outcomes in critically ill patients reliant on life-sustaining respiratory support. These responsibilities extend from initial assessment through weaning protocols, emphasizing evidence-based practices that mitigate complications like ventilator-associated pneumonia (VAP), ensure patient-ventilator synchrony, and facilitate safe liberation from mechanical ventilation. By leveraging interdisciplinary collaboration and standardized bundles, nurses significantly influence weaning success rates, reduce ICU length of stay, and enhance patient safety across diverse clinical scenarios (Higginson, 2011).

Nurses perform comprehensive patient assessments and continuous monitoring as the cornerstone of mechanical ventilation management, systematically evaluating vital signs, ventilator parameters, and physiological responses to detect subtle deteriorations early and prevent adverse events such as desynchrony or hemodynamic instability. This involves hourly checks of respiratory rate, tidal volume, peak pressures, end-tidal CO2, pulse oximetry, and arterial blood gases, correlated with physical exam findings like chest auscultation, mucous membrane color, and level of consciousness, while applying tools like Kirby's Rule of 20 for holistic evaluation of trends in temperature, perfusion, oxygenation, and mentation. Advanced practice nurses integrate data from chest radiographs, electrolyte panels, acid-base status, and nutrition to formulate dynamic care plans, troubleshooting alarms for low tidal volumes or pressure changes by verifying endotracheal tube patency, cuff integrity, and circuit connections, often employing point-of-care ultrasound (POCUS) for rapid detection of pneumothorax, pleural effusions, or B-lines indicative of evolving respiratory distress. In neonatal or adult ICUs, nurses interpret ventilator waveforms for patient-ventilator asynchrony, adjust FiO2 temporarily to 100% during acute issues before manual bagging for reassessment, and document trends to guide weaning readiness, ensuring compliance with protocols that incorporate daily spontaneous breathing trials (SBTs) coordinated with sedation interruptions for optimal timing. This vigilant, multifaceted monitoring not only enhances compliance and minute ventilation evaluation but also empowers nurses to advocate for timely interventions, reducing risks of prolonged ventilation and associated morbidities through proactive identification of changes in effort, synchrony, or gas exchange parameters (Meitner et al., 2023).

Airway management and troubleshooting strategies represent a critical nursing domain in mechanical ventilation, where nurses maintain endotracheal or tracheostomy tube patency, secure devices to prevent accidental extubation, and respond swiftly to alarms signaling obstructions, dislodgements, or leaks through systematic protocols that prioritize patient safety and ventilator efficacy. Routine interventions include verifying cuff pressures (typically 20-30 cmH2O), performing endotracheal suctioning with pre-oxygenation and hyperinflation to minimize hypoxia and trauma, and employing closed suction systems to reduce VAP risk while assessing for tube migration via chest X-ray confirmation and minimal occlusive dressing securement. Troubleshooting escalates with high-pressure alarms prompting checks for bronchospasm, secretions, or kinking, low-volume alarms indicating cuff leaks or disconnections, and immediate manual ventilation via bag-valve-mask to assess compliance and rule out tension pneumothorax, often integrating capnography for waveform analysis and POCUS for real-time diagnostics. Nurses also facilitate tracheostomy care, including inner cannula cleaning, stoma inspection, and humidification optimization to combat circuit drying, while collaborating with respiratory therapists on cuff deflation trials during weaning to evaluate swallowing and cough reflexes, ensuring seamless transitions to non-invasive support. These strategies, grounded in evidence-based bundles, underscore nurses' pivotal role in averting airway crises, promoting synchrony through mode-specific adjustments like pressure support ventilation (PSV), and supporting extubation readiness via cuff leak tests and neurological assessments (Meitner et al., 2023).

Infection prevention and ventilator-associated event (VAE) reduction form a core nursing responsibility in mechanical ventilation, executed through rigorous adherence to VAP bundles that encompass head-of-bed elevation at 30-45 degrees, daily sedation vacations, oral care with chlorhexidine every 6-8 hours, subglottic suctioning, and meticulous hand hygiene to interrupt pathogen transmission and biofilm formation in the endotracheal tube. Nurses champion daily readiness-to-wean assessments, prioritizing early mobility protocols with progressive sitting, standing, and ambulation to enhance clearance of secretions, improve ventilation-perfusion matching, and counteract immobility-induced atelectasis, while strictly enforcing zero-tolerance for ventilator circuit breaks and promoting non-invasive ventilation (NIV) trials to minimize intubation duration. Compliance with these multifaceted interventions directly correlates with reduced VAE incidence, shorter mechanical ventilation days (from 12 to 9 in compliant cohorts), and lower mortality, as nurses monitor for early VAE signs like sustained positive fluid balance or worsening oxygenation via daily PEPA scoring. By fostering interprofessional teamwork, optimizing nurse-patient ratios, and auditing bundle adherence, nurses drive quality improvements, leveraging nurse-led protocols to achieve VAP rates below benchmark thresholds and ensuring environmental controls like cohorting and device sterilization (Al-Harthi et al., 2025).

Sedation, pain, and comfort management in mechanically ventilated patients demand precise nursing titration guided by validated scales like Richmond Agitation-Sedation Scale (RASS), Critical-Care Pain Observation Tool (CPOT), and Confusion Assessment Method for ICU (CAM-ICU), prioritizing analgesia-first strategies with opioids (e.g., fentanyl boluses pre-procedure) before sedatives (propofol or dexmedetomidine infusions) to achieve light sedation targets (RASS -1 to 0) that facilitate daily interruptions and SBTs without risking self-extubation or delirium. Nurses conduct q4-6h assessments, preemptively dosing for noxious stimuli like suctioning or repositioning, while monitoring for oversedation pitfalls or undersedation distress, adjusting via goal-directed protocols that incorporate ABCDE bundles (Awakening and Breathing Coordination, Delirium monitoring, Early mobility). Multidisciplinary rounds refine targets based on trajectory, with nurse-driven algorithms reducing benzodiazepine use, opioid exposure duration, and iatrogenic withdrawal, as evidenced in pediatric and adult trials showing safer outcomes and cost savings through vigilant endpoint evaluation. Comfort extends to environmental modulation to mitigate anxiety, ensuring physiological stability (HR 60-100, RR 12-20, SpO2 >95%) and calm behaviors, thus optimizing weaning success and psychological well-being (Grap et al., 2012).

Nutrition, positioning, and skin integrity maintenance are integral nursing roles in mechanical ventilation, where early enteral feeding via post-pyloric tubes (initiated within 24-48 hours) supports gut integrity and weaning tolerance, with nurses monitoring residuals (<250 mL), glycemic control, and protein delivery (1.2-2.0 g/kg/day) to combat catabolism without aspiration risks mitigated by blue-dye-free prokinetics and continuous low-rate infusions. Optimal positioning enhances V/Q matching, secretion drainage, and pressure redistribution, with nurses employing air pillows, lateral tilts q2h, and specialized surfaces to avert pressure injuries (PIs) on high-risk areas like forehead, chin, and heels, conducting Braden Q or NPUAP assessments alongside moisture barrier creams and foam dressings. Prone protocols demand meticulous skin inspections pre/post-maneuver, addressing shear from lines/tubes and MASD from secretions, while early mobility (passive range-of-motion to progressive ambulation) boosts perfusion, reduces PI incidence (RR 1.22 supine vs. prone), and accelerates liberation, integrating POCUS for fluid status. These interventions, per nurse-led plans, preserve tissue viability, sustain nutritional endpoints despite ventilator dependence, and align with bundles minimizing complications in prolonged cases (Fourie et al., 2021).

Documentation, handovers, and communication continuity ensure seamless mechanical ventilation care, with nurses meticulously charting ventilator settings, ABG trends, bundle compliance, and weaning parameters in electronic health records using SBAR (Situation-Background-Assessment-Recommendation) frameworks to facilitate shift transitions and multidisciplinary briefings. Standardized handover protocols minimize omissions, reducing interruptions and workload while boosting satisfaction, as bedside verbal/written transfers cover airway status, sedation goals, mobility progress, and family updates. Communication with ventilated patients employs tools like picture boards, lip-reading, or apps for needs expression, with nurses initiating interactions to alleviate frustration (98% report barriers), fostering psychological safety amid nonverbal cues. These practices enhance team behaviors, information fidelity, and outcomes like reduced errors in polytrauma weaning, upholding continuity from OR-to-ICU through audit-driven refinements (Schianchi & Harris, 2025).

Weaning Protocols in Practice

Weaning from mechanical ventilation represents a critical phase in critical care, where structured protocols guide the transition from full ventilatory support to spontaneous breathing, minimizing complications like ventilator-associated pneumonia and muscle atrophy while optimizing patient outcomes. Nurses play a pivotal role in implementing these protocols, conducting readiness assessments, monitoring spontaneous breathing trials (SBTs), and titrating support based on evidence-based indices, which collectively reduce mechanical ventilation duration by up to 26% compared to non-protocolized care(West et al., 2009).

The evolution of weaning protocols traces back to the 1970s when synchronized intermittent mandatory ventilation (SIMV) dominated as the primary weaning mode, often involving abrupt disconnections from the ventilator for short periods every 30 minutes to test tolerance, a method prone to patient distress and inconsistent outcomes. By the 1980s, studies on patient-ventilator interactions exposed SIMV's limitations, prompting a shift toward pressure support ventilation (PSV) and other gradual modes; the mid-1990s marked pivotal randomized controlled trials involving nearly 1000 patients that validated standardized protocols, demonstrating reduced ventilation duration, lower reintubation rates, and cost savings in medical and cardiac ICUs. Implementation of these early protocols, modified from models like Ely et al., incorporated tools such as the Richmond Agitation-Sedation Scale and aggressive SBT progression, leading to measurable declines in ICU length of stay from 8.6 to 7.9 days over implementation periods (Akella et al., 2022).

Nurse-led weaning protocols consistently outperform physician-led approaches in reducing mechanical ventilation duration, with meta-analyses of randomized controlled trials showing a mean reduction of 1.78 days (95% CI -3.08 to -0.48), alongside shorter ICU and hospital lengths of stay, without increasing failed weaning rates or mortality. In direct comparisons, nurse-led groups achieved mean ventilation times of 111.75 hours versus 125.12 hours in physician-driven groups (P=0.000), attributed to nurses' frequent bedside assessments using tools like the Burns Wean Assessment Program (BWS), enabling timely SBT initiation. Protocol-driven nurse involvement fosters interprofessional collaboration, with 85% of ICUs reporting shared decision-making for weaning readiness when protocols are used, enhancing efficiency in tracheostomized and difficult-to-wean patients (Y.-C. Lin et al., 2025).

The Rapid Shallow Breathing Index (RSBI), calculated as respiratory rate divided by tidal volume (breaths/min/L), remains a cornerstone predictor with a cutoff >105 indicating SBT failure risk, validated across ventilators and outperforming alternatives like Pimax in area under the curve analyses (AUC 0.637 for RSBI vs. 0.545 for Pimax). The Burns Wean Assessment Program (BWAP), particularly its modified version (m-BWAP), integrates multiple parameters including oxygenation, hemodynamics, and mental status, achieving positive predictive values of 76% and negative values of 64% for weaning success at first SBT, superior to isolated indices in prolonged ventilation scenarios. Integrative Weaning Index (IWI) scores ≥25 trigger T-piece SBTs, correlating strongly with outcomes and surpassing BWAP in some cohorts, underscoring nurses' utility in scoring these at bedside to guide protocol adherence (Rittayamai et al., 2021).

Weaning unfolds in structured stages: initial readiness screening (e.g., PaO_2/FiO_2 >150, PEEP ≤8 cmH_2O), followed by SBTs via T-piece, CPAP matching prior PEEP, or low pressure support (5-8 cmH_2O), lasting 30-120 minutes to assess tolerance without fatigue. Success on first SBT occurs in 75% of ready patients, but early trials highlight risks of delayed recognition; protocols mandate daily assessments before noon, avoiding FiO_2 increases, with failure defined by respiratory distress or vital sign instability prompting support resumption. For prolonged cases, slow-paced trials with gradual lengthening predominate, reducing reintubation through nurse-monitored progression from PSV to full spontaneous breathing (Zein et al., 2016).

Daily sedation interruption (DSI), or "sedation vacation," evaluates neurological status and weaning readiness, shortening ventilation by optimizing arousal without distress, applied every 2 hours using scales like RASS or COMFORT in 59% of units. Protocols pair DSI with readiness criteria (e.g., minimal secretions, stable hemodynamics), performed daytime to avoid nocturnal risks, with 86% citing neurological assessment as primary goal and 44% targeting ventilation reduction. In pediatric and adult ICUs, DSI-integrated weaning accelerates extubation, as evidenced by feasibility studies emphasizing nurse-led COMFORT scoring and interprofessional target-setting (Blackwood et al., 2019).

Collaborative models dominate, with 63-88% of ICUs sharing ventilator setting and weaning decisions between nurses and physicians, amplified by protocols (odds ratio 1.8-1.9 for key steps like extubation readiness). Escalation criteria include RSBI >105 at 2-15 minutes, MV-RDOS distress signals, or vital sign thresholds (HR >140, RR >35), prompting immediate support reinstatement and protocol review. Nurse-driven algorithms, validated in RCTs, incorporate failure predictors like high tidal volume or rapid shallow breathing in emergency settings, ensuring safe progression while minimizing delays (Decavèle et al., 2022).

Special Populations and Clinical Adaptations

Nursing roles in neonatal and pediatric mechanical ventilation weaning emphasize protocol-driven approaches tailored to the unique physiological vulnerabilities of these populations, including immature lung development, small tidal volumes, high respiratory rates, and risks of complications like bronchopulmonary dysplasia (BPD) and ventilator-induced lung injury (VILI). In neonates, particularly preterm infants, weaning begins with assessing readiness through clinical stability, adequate gas exchange on minimal settings (e.g., low peak inspiratory pressure [PIP] and positive end-expiratory pressure [PEEP]), and spontaneous breathing trials (SBTs) lasting 30-120 minutes on continuous positive airway pressure (CPAP) or pressure support ventilation (PSV), where nurses monitor heart rate variability (HRV), respiratory variability index (RVI), oxygen saturation, and signs of distress to predict extubation success with high sensitivity. Pediatric protocols often incorporate synchronized intermittent mandatory ventilation (SIMV) transitioning to PSV, with nurses leading daily readiness screens using criteria like stable hemodynamics, pH >7.25, PaCO2 <50-60 mmHg, and FiO2 <0.4-0.5, reducing weaning duration by standardizing reductions in ventilator rate and support while preventing reintubation rates of 10-40% through vigilant post-extubation monitoring with non-invasive support like nasal CPAP or high-flow nasal cannula (HFNC). Evidence from quality improvement initiatives highlights nurse-led checklists that coordinate multidisciplinary extubation timing, minimizing unplanned extubations and accelerating liberation, though challenges persist due to heterogeneous practices across neonatal intensive care units (NICUs) and pediatric ICUs (PICUs), where protocolized weaning shows promise in shortening invasive ventilation time without increasing adverse events like air leaks or neurodevelopmental impairment (Wielenga et al., 2016).

In geriatric patients, frailty significantly impacts weaning success due to age-related declines in respiratory muscle strength, sarcopenia, comorbidities like heart failure, and altered chest wall compliance, necessitating nurses to integrate frailty scales (e.g., Clinical Frailty Scale) into daily assessments alongside traditional parameters like rapid shallow breathing index (RSBI <105) and SBT tolerance to customize weaning protocols that prioritize gradual pressure support reductions and early mobilization. Nurses play a pivotal role in identifying high-risk elderly patients through comprehensive geriatric assessments, implementing tailored interventions such as nutritional optimization, inspiratory muscle training, and multimodal analgesia to mitigate weaning failure rates, which can exceed 40% in frail individuals, while monitoring for complications like delirium and aspiration. Protocolized approaches in these populations emphasize nurse-driven spontaneous awakening trials (SATs) combined with SATs, reverse Trendelenburg positioning to reduce diaphragmatic load, and post-extubation high-flow nasal oxygen to support prolonged recovery phases, with evidence indicating frailty has a more consistent negative influence on delayed weaning and reintubation than chronological age alone, though outcomes improve once separation attempts commence under structured nursing oversight (Yayan et al., 2024).

For patients with acute respiratory distress syndrome (ARDS), obesity, and those requiring prone positioning, nursing management focuses on protective ventilation strategies using low tidal volumes (4-6 mL/kg predicted body weight), high PEEP (10-20 cmH2O), and recruitment maneuvers, where nurses meticulously titrate settings based on esophageal pressure monitoring or driving pressure to optimize transpulmonary pressure while facilitating weaning through daily SBTs adapted for obesity-related atelectasis and reduced functional residual capacity. In obese ARDS patients, nurses coordinate prone positioning (12-16 hours/day in severe cases) to enhance dorsal lung recruitment, improve ventilation-perfusion matching, and shorten mechanical ventilation duration, addressing challenges like increased intra-abdominal pressure and difficult airway management by employing reverse Trendelenburg for weaning trials and ensuring safe proning-proning cycles with skin integrity checks and hemodynamic stability. These adaptations reduce ventilator days and mortality risks, as obesity predisposes to prolonged ventilation yet responds well to higher PEEP and prone therapy, with nurses leading protocolized transitions to non-invasive ventilation post-extubation to prevent reintubation in this high-risk cohort (De Jong et al., 2020).

Patients with chronic obstructive pulmonary disease (COPD) and neuromuscular disorders require nuanced weaning protocols emphasizing gradual pressure support ventilation (PSV) reductions or synchronized intermittent mandatory ventilation (SIMV) with close monitoring of auto-PEEP and respiratory muscle fatigue, where nurses assess readiness using diaphragmatic ultrasound, maximal inspiratory pressure (MIP >-20 to -30 cmH2O), and vital capacity (>10-15 mL/kg) to tailor interventions like non-invasive ventilation

(NIV) bridges post-extubation. In neuromuscular disease, the lack of specific protocols heightens weaning challenges due to progressive muscle weakness and hypoventilation, prompting nurses to implement cough assist techniques, tracheostomy considerations for prolonged dependence, and early NIV with bilevel positive airway pressure (BiPAP) to reduce reintubation risks and ICU stays, particularly in conditions like amyotrophic lateral sclerosis or myasthenia gravis. For COPD, nurses focus on bronchodilator optimization, smoking cessation counseling during recovery, and SBTs on T-piece or low PSV (5-8 cmH2O), achieving comparable success rates across methods while minimizing dynamic hyperinflation (Dolinay et al., 2024).

Prolonged mechanical ventilation (PMV), defined as >14-21 days, demands interdisciplinary nurse-led protocols in long-term acute care settings, incorporating tracheostomy facilitation, daily SAT/SBT cycles, and advanced diagnostics like electrical activity of the diaphragm (EAdi) via neurally adjusted ventilatory assist (NAVA) to overcome multifactorial dependence from pulmonary mechanics derangements, critical illness neuromyopathy, and comorbidities. Nurses drive weaning through structured diaries tracking progressive PSV downtitration, nutritional support to combat catabolism, physical therapy for muscle retraining, and vigilant surveillance for ventilator-associated pneumonia (VAP), achieving liberation rates of 50-70% via protocolized care that halves weaning duration compared to physician-directed methods. In PMV cohorts, post-extubation prone positioning or NIV enhances tolerance, particularly in chronic lung disease subsets, underscoring nurses' role in sustaining gains from initial ventilation phases to prevent chronic ventilator dependence and optimize quality of life (Surani et al., 2020).

Challenges and Ethical Considerations

Predictors of weaning failure and complications remain a central challenge in mechanical ventilation management, as up to 25-30% of critically ill patients experience difficult weaning, leading to reintubation rates of 10-20% and associated risks including ventilator-associated pneumonia, diaphragmatic dysfunction, prolonged ICU stays, and increased mortality. Key predictors identified across systematic reviews include physiological parameters such as rapid shallow breathing index (RSBI >105), elevated respiratory rates, reduced diaphragm thickening fraction and excursion, low P/F ratios, and scores like APACHE III or SOFA on day 21 of ventilation, with machine learning models and imaging also emerging as comprehensive tools. Complications arise from respiratory factors like increased airway resistance (bronchospasm, secretions), decreased compliance (edema, ARDS), and cardiac strain causing pulmonary edema due to heightened adrenergic tone, hypoxemia, and work of breathing, while patient-specific risks such as age, respiratory etiology of admission, COPD, Charlson Comorbidity Index, and multiple organ dysfunction syndrome further elevate failure odds in prolonged mechanical ventilation (PMV) cases. Nurses play a pivotal role in early identification through daily assessments, yet heterogeneous prediction scores (e.g., RSBI, CROP index, Morganroth scale) show variable specificity, underscoring the need for integrated, nurse-led protocols to balance premature extubation risks against MV prolongation harms like barotrauma and delirium (Sterr et al., 2024).

Resource limitations and workload strain significantly impede effective weaning protocols in ICUs, where only 46% of available ventilator shifts are utilized for weaning despite protocol directives, exacerbated by night shifts, high nursing workloads, and under-resourced environments particularly in low- and middle-income countries. In resource-constrained settings, staffing shortages, variable nurse-to-patient ratios, and limited access to respiratory therapists force prioritization of acutely deteriorating patients over weaning, leading to delays that prolong MV duration by up to 40-50%, increase ICU resource consumption (up to 37% for PMV patients), and heighten complications like ventilator-induced diaphragmatic dysfunction and venous thromboembolism. Nurse-led protocols (NLPW) demonstrate potential to shorten weaning time and MV duration through standardized assessments and spontaneous breathing trials (SBTs), yet barriers including inadequate training, interprofessional silos, protocol invisibility, and organizational culture hinder implementation, with historical controls showing higher APACHE-II scores yet improved outcomes via targeted interventions like blended learning on weaning criteria. These strains disproportionately affect

PMV patients requiring >21 days of support, where economic burdens and futility risks demand systemic adaptations such as workflow integration and physician endorsement to foster sustainability, especially in developing regions facing financial toxicity from extended stays (Menguy et al., 2023).

Ethical decision-making in withdrawal, prolonged MV, and palliative transitions demands balancing autonomy, beneficence, non-maleficence, and justice, as ventilator withdrawal from non-terminally imminently dying patients raises moral justifications when burdens outweigh benefits, yet clinician ambivalence persists due to fears of euthanasia accusations despite legal protections via ethics committees. Prolonged MV (>21 days) often leads to poor survival, chronic disability, and high family caregiving demands, prompting end-of-life decisions like withholding intubation, do-not-resuscitate orders, or NIV ceilings, with palliative care integration reducing intensive treatments and improving quality of life though infrequently delivered beyond pain management. Nurses and multidisciplinary teams must navigate dilemmas such as family surrogate involvement, patient wishes, and prognosis uncertainty, employing routine ethics consultations and communication frameworks to align care with values, while terminal weaning requires humane protocols addressing dyspnea (affecting 75% of dying patients) via comfort-focused MV rather than prolongation. In PMV contexts, futility-oriented treatment cessation, symptom management, and transitions to high-dependency units or hospices ethical imperative, particularly when recovery is unlikely, emphasizing shared decision-making to mitigate moral distress (Ambrosino & Vitacca, 2018).

Legal accountability and documentation standards in weaning processes safeguard clinicians through institutional protocols that detail ventilator termination procedures, incorporating ethics committee concurrence to shield against civil or criminal liability as established in landmark cases like Quinlan, where privacy rights justified withdrawal. Nurses bear responsibility for precise charting of weaning readiness assessments, SBT outcomes, physician prescriptions (or independent protocol actions), and interprofessional decisions on settings like PEEP, pressure support, and FiO_2, with discrepancies in decisional hierarchies risking delays or errors. Comprehensive records must capture patient preferences, family discussions, and futility rationales to support withdrawal legitimacy, while protocolized approaches (nurse-led vs. physician judgment) enhance defensibility by standardizing practices and reducing variability, as evidenced in pilots showing shorter MV durations. In PMV and palliative shifts, documentation of surrogate consensus, multidisciplinary involvement, and palliative metrics ensures compliance amid evolving laws prioritizing patient-centered autonomy over default prolongation (Rose et al., 2011).

Family-centered communication during weaning fosters trust, motivation, and success by integrating relatives at the bedside for 46% of trials, where they provide touch, encouraging talk, and interpretive surveillance of monitors, mimicking clinician behaviors to enhance patient comfort and safety. Scheduled family presence accelerates weaning in brain injury cases via relaxation and supervision, while persistent nurse-family-patient interactions build mutual understanding, explore emotions, and align care with holistic needs, countering voicelessness challenges. Nurses facilitate this through clear prognostic explanations, shared protocol prompts, and transitional planning in family meetings for PMV patients, reducing surrogate-physician discord and emotional burdens while promoting ethical consensus on outcomes like disability risks. In palliative transitions, empathetic dialogues address expectations mismatches, with family partnership in interventions like hypnosis further aiding respiratory autonomy and ventilator liberation (Salmani et al., 2022).

Future Directions and Research Gaps

AI-driven decision support systems and tele-ICU applications represent transformative advancements in mechanical ventilation weaning, empowering nurses to leverage real-time data analytics for precise patient assessments and remote oversight. These technologies integrate machine learning algorithms that analyze vast datasets from ventilator parameters, vital signs, and physiological trends to predict weaning readiness with high accuracy, often outperforming traditional clinician judgment alone by reducing mechanical ventilation duration by up to 21 hours and shortening ICU length of stay. In tele-ICU settings, nurses can access centralized dashboards that provide graphical visualizations of patient status, facilitating proactive interventions even from off-site locations, which is particularly beneficial in understaffed units or during pandemics like COVID-19 where remote monitoring minimized exposure risks while maintaining weaning success rates. Studies have demonstrated that AI systems, such as those using two-stage prediction models, achieve positive predictive values exceeding 89% for weaning trials, surpassing conventional methods like the Rapid Shallow Breathing Index, and enable automated adjustments in pressure support ventilation to synchronize with patient efforts. Furthermore, nurse-led integration of these tools enhances interdisciplinary communication, as predictive dashboards allow for data-driven discussions with physicians and families, ultimately lowering reintubation rates and ventilator-associated events through timely, evidence-informed decisions (Y.-H. Lin et al., 2024).

Predictive analytics for weaning readiness harness advanced machine learning models to evaluate multifaceted parameters including heart rate variability, plethysmographic waveforms, and spontaneous breathing trial data, offering nurses probabilistic forecasts of extubation success that guide protocol adherence. These analytics incorporate temporal, frequency, and non-linear domain analyses from photoplethysmography curves alongside respiratory metrics like the Early-Warning Score Oxygen, achieving areas under the receiver operating characteristic curve above 0.87 for distinguishing successful from failed weaning outcomes. By focusing solely on ventilator-derived data during spontaneous breathing trials, such models eliminate the need for additional clinician computations, providing instant bedside probabilities that streamline nursing workflows and reduce premature or delayed extubations. Research highlights their superiority over single-parameter indices, with evolutionary algorithms and symbolic regression validating models on large cohorts that predict weaning success across diverse ICU populations, including those with prolonged ventilation. Nurses benefit from these tools by gaining confidence in autonomous assessments, as real-time updates on weaning likelihood support personalized weaning trajectories, potentially cutting ICU stays and mortality risks associated with ventilator dependency (Menguy et al., 2023).

Digital protocols and bedside automation in mechanical ventilation care automate weaning processes through intelligent ventilators like SmartCare and Adaptive Support Ventilation, which dynamically adjust support levels based on minute ventilation targets and patient comfort zones defined by respiratory rate, tidal volume, and end-tidal CO2. These systems conduct automated spontaneous breathing trials with minimal pressure support, demonstrating higher predictive accuracy (89%) than physician-directed approaches, while nurse-led protocols embedded in computerized decision support further optimize outcomes by enforcing evidence-based rules for PEEP, FiO2, and tidal volume adjustments. Bedside automation reduces variability in care delivery, as real-time feedback via tablet interfaces visualizes trends in ventilator-associated events, enabling nurses to intervene swiftly and achieve adherence rates that shorten ventilation times by 26% or more. Integration with hospital information systems allows for drill-down analytics on weaning phases, supporting transitions from controlled to assist modes and facilitating nurse empowerment in complex cases like pediatric ARDS. Such digital tools not only mitigate human error but also track protocol compliance longitudinally, fostering continuous quality improvement in respiratory therapy practices (Stivi et al., 2024).

Research gaps persist notably in low- and middle-income countries (LMICs), where studies on mechanical ventilation weaning are scarce, limiting generalizability of AI and protocol findings from high-resource settings to resource-constrained environments with higher burdens of ventilator-associated pneumonia and prolonged weaning. In LMICs, factors like inconsistent staffing, limited access to advanced ventilators, and variable training exacerbate weaning failures, yet few trials address these contextual barriers, with most evidence derived from high-income cohorts showing nurse-led protocols reduce duration but untested in under-resourced ICUs. Outcomes of staff role expansion, such as empowering nurses for autonomous weaning decisions, require more longitudinal data on sustainability, burnout, and long-term patient metrics like 90-day mortality, as pilot studies indicate feasibility but lack multicenter validation across diverse case mixes. Gaps also include integration of multimodal ultrasound with AI for diaphragmatic assessment in difficult weaning cases and evaluation of weaning indices in heterogeneous populations, including neonates and tracheostomized patients, where current models underperform without LMIC-specific thresholds (Sepúlveda et al., 2025).

Policy recommendations for global nursing standardization advocate for mandatory integration of AI-driven tools and nurse-led protocols into ICU training curricula, with international bodies like the World Health Organization endorsing unified weaning bundles adaptable to LMIC contexts through scalable tele-ICU networks. Standardized policies should prioritize evidence-based bundles like the National Approach to Standardize and Improve Mechanical Ventilation, which target ventilator-associated events via objective criteria and nurse empowerment, extended to 70-100 ICUs for nationwide impact. Global frameworks must emphasize safety culture metrics, ongoing education in predictive analytics, and resource allocation for bedside automation to bridge high-low income disparities, ensuring protocols reduce reintubation and enhance outcomes universally. Recommendations include multicenter RCTs for role expansion validation, cost-effectiveness analyses in LMICs, and policy incentives for digital infrastructure to support nurse autonomy in weaning, fostering equitable respiratory care worldwide (Y.-C. Lin et al., 2025).

Conclusion

Nurse-led weaning protocols consistently reduce mechanical ventilation duration by 1-2 days, ICU length of stay, and complications like ventilator-associated pneumonia compared to physician-driven approaches, as evidenced by meta-analyses of randomized trials. The "Mechanical Ventilation and Beyond" framework positions nurses as central to the full continuum addressing gaps in patient-centered outcomes such as comfort, delirium prevention, and quality of life. Future directions include AI predictive analytics, tele-ICU integration, and LMIC-adapted policies to enhance generalizability, training, and resource equity while overcoming implementation barriers like workload and cultural silos.

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