AARC Clinical Practice Guideline: Patient-Ventilator Assessment

Lynda T Goodfellow, Andrew G Miller, Sarah M Varekojis, Carolyn J LaVita, Joel T Glogowski, and Dean R Hess

Given the important role of patient-ventilator assessments in ensuring the safety and efficacy of mechanical ventilation, a team of respiratory therapists and a librarian used Grading of Recommendations, Assessment, Development, and Evaluation methodology to make the following recommendations: (1) We recommend assessment of plateau pressure to ensure lung-protective ventilator settings (strong recommendation, high certainty); (2) We recommend an assessment of tidal volume (V_T) to ensure lung-protective ventilation (4–8 mL/kg/predicted body weight) (strong recommendation, high certainty); (3) We recommend documenting V_T as mL/kg predicted body weight (strong recommendation, high certainty); (4) We recommend an assessment of PEEP and auto-PEEP (strong recommendation, high certainty); (5) We suggest assessing driving pressure to prevent ventilator-induced injury (conditional recommendation, low certainty); (6) We suggest assessing F_{IO_2} to ensure normoxemia (conditional recommendation, very low certainty); (7) We suggest telemonitoring to supplement direct bedside assessment in settings with limited resources (conditional recommendation, low certainty); (8) We suggest direct bedside assessment rather than telemonitoring when resources are adequate (conditional recommendation, low certainty); (9) We suggest assessing adequate humidification for patients receiving noninvasive ventilation (NIV) and invasive mechanical ventilation (conditional recommendation, very low certainty); (10) We suggest assessing the appropriateness of the humidification device during NIV and invasive mechanical ventilation (conditional recommendation, low certainty); (11) We recommend that the skin surrounding artificial airways and NIV interfaces be assessed (strong recommendation, high certainty); (12) We suggest assessing the dressing used for tracheostomy tubes and NIV interfaces (conditional recommendation, low certainty); (13) We recommend assessing the pressure inside the cuff of artificial airways using a manometer (strong recommendation, high certainty); (14) We recommend that continuous cuff pressure assessment should not be implemented to decrease the risk of ventilator-associated pneumonia (strong recommendation, high certainty); and (15) We suggest assessing the proper placement and securement of artificial airways (conditional recommendation, very low certainty). *Key words: Guidelines; Mechanical Ventilation; Evidence-Based Respiratory Care; Patient assessment; Physical examination; Adjustments; Stability; Safety; Trends; Auscultation; Patient distress; Dyspnea.* [Respir Care 2024;69(8):1042–1054. © 2024 Daedalus Enterprises]

Introduction

Clinicians assess patients requiring mechanical ventilation at regular intervals as part of a patient-ventilator assessment (PVA). This has historically been called a ventilator system check, ventilator check, or other local descriptions.[1] These terms do not emphasize the importance of evaluating the patient and do not encompass all the essential aspects of ensuring patient safety while receiving noninvasive ventilation (NIV) or invasive mechanical ventilation. The PVA is important to ensure effectiveness and safety of mechanical ventilation. We use the following definition of PVA for this clinical practice guideline (CPG): A PVA is a comprehensive assessment, done at regular intervals by a clinician, for a patient receiving NIV or invasive mechanical ventilation. It includes an assessment by physical examination of bedside physiologic data, of the airway, of ventilator settings and monitoring from the ventilator, and of humidification. These assessments are used to modify care as needed. It also includes documentation of these findings and modifications of care in the medical record. More detailed components of a PVA are shown in Figure 1. Most importantly, the focus of a PVA is on the patient rather than the ventilator.

The American Association for Respiratory Care (AARC) published a CPG entitled "Patient-Ventilator System Checks" in 1992.[2] The evidence related to PVA has evolved since that time, but questions remain. There is a need for an updated CPG to improve clinical practice and guide clinicians worldwide. By focusing on key assessments and observations performed by skilled bedside clinicians, patient outcomes can be improved. In 2003, Akhtar et al[3] reported considerable variability in documentation practices by respiratory therapists (RTs) caring for patients receiving mechanical ventilation. Also, important aspects of lung-protective ventilation such as plateau pressure (P_{plat}) and other parameters are recorded inconsistently.[4,5] A British study published during the COVID-19 pandemic assessed current practices on a global scale and reported data from 40 countries across 6 continents.[6] The authors found that ventilator support practices varied greatly, with limited use of standardized protocols. Furthermore, most clinicians were dependent upon isolated and wide-ranging management guidelines in caring for patients with COVID-19.

Despite the CPG published in this Journal in 1992,[2] variations in practice related to PVAs are pervasive. PVAs must be aligned with best practices. The purpose of this CPG is to provide evidence-based recommendations that impact patient care. Second, the important role that bedside clinicians demonstrate through their assessments needs to be further stressed.

Methods

Clinical Practice Guidelines Panel Composition and Disclosures

The methodologist, in consultation with the managing editor of RESPIRATORY CARE, identified potential panelists based on demonstrated expertise in critical care, affiliation with an academic medical center, and potential to contribute to a systematic review on PVA. The panel consisted of 6 RTs and a health sciences librarian with experience performing systematic literature reviews. Conflict-of-interest disclosure forms were reviewed, and no disqualifying conflicts were noted (see related supplementary materials at http://www.rcjournal.com).

Formulation of PICO Questions and Outcomes Prioritization

At the initial meeting, all members participated in a free association discussion about PVA. From this exercise, clinical questions were chosen based on perceived

Dr Goodfellow is Director of AARC Clinical Practice Guideline Development and is affiliated with American Association for Respiratory Care/Daedalus Enterprises, Irving, Texas, and Georgia State University, Atlanta, Georgia. Mr Miller is affiliated with Duke University Medical Center, Durham, North Carolina. Dr Varekojis is affiliated with The Ohio State University, Columbus Ohio. Ms LaVita is affiliated with Massachusetts General Hospital, Boston, Massachusetts. Mr Glogowski is affiliated with Georgia State University, Atlanta, Georgia. Dr Hess is affiliated with Massachusetts General Hospital, Boston, Massachusetts; and Daedalus Enterprises, Irving, Texas.

Mr Miller discloses relationships with the Board of Directors for the Carolina/Virginias Chapter of Society of Critical Care Medicine, Saxe Communication, Fisher & Paykel, S2N Health, MedEx Research, and Aerogen. Mr Miller is a section editor for RESPIRATORY CARE. Dr Varekojis discloses relationships with The Ohio State University, the Commission on Accreditation for Respiratory Care, and American Association for Respiratory Care/Daedalus Enterprises. Dr LaVita discloses relationships with Orange Medical-Nihon Kohden, Timpel, and VERO Bio Tech. Mr Glogowski discloses a relationship with Georgia State University. Dr Goodfellow discloses relationships with the American Association for Respiratory Care/Daedalus Enterprises and Georgia State University. Dr Hess discloses a relationship with the American Association for Respiratory Care/Daedalus Enterprises, Massachusetts General Hospital, Northeastern University, Lungpacer, Jones & Bartlett, McGraw Hill, UpToDate, and the University of Pittsburgh. Dr Hess is managing editor for RESPIRATORY CARE.

Supplementary material related to this paper is available at http://www.rcjournal.com.

Correspondence: Lynda T Goodfellow EdD RRT FAARC, American Association for Respiratory Care, 9425 N. MacArthur Boulevard, Suite 100, Irving, TX 75063–4706. E-mail: Lynda.goodfellow@aarc.org.

DOI: 10.4187/respcare.12007

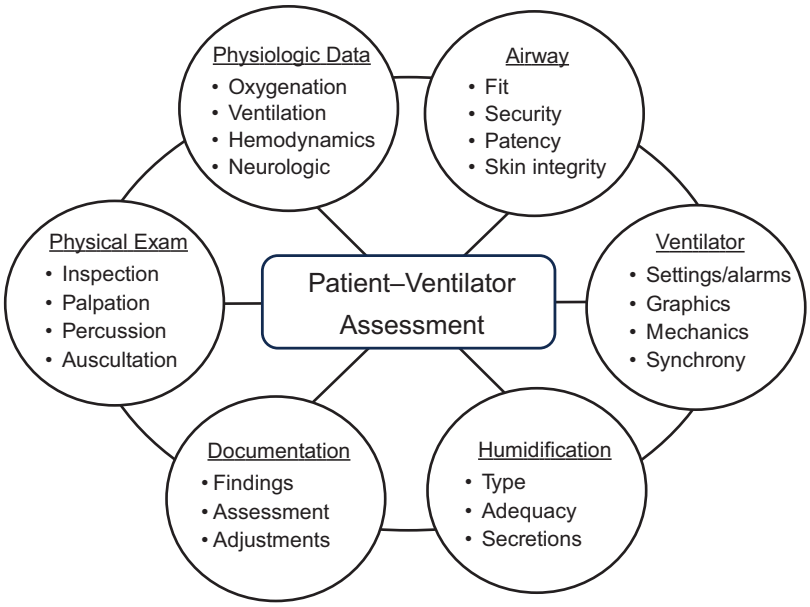

Fig. 1. Essential components of a patient-ventilator assessment.

Table 1. Details for Population, Intervention, Comparators, and Outcomes Questions That Are Addressed in this Clinical Practice Guideline

	Population	Intervention	Comparison	Outcome
1	Patients receiving invasive mechanical ventilation.	Assessment of lung-protective ventilation.	No assessment of lung-protective ventilation.	Mortality
2	Patients receiving noninvasive or invasive mechanical ventilation.	Remote (telehealth) PVA.	Bedside assessment.	Concordance with bedside assessment, cost, patient satisfaction
3	Patients receiving noninvasive or invasive mechanical ventilation.	Assessing patients for adequate humidity.	Not assessing patients for adequate humidity.	Airway occlusion, cost, pneumonia, mortality
4	Patients receiving noninvasive or invasive mechanical ventilation.	Assessing the artificial airway/interface.	Not assessing the artificial airway/interface.	Skin breakdown, airway injury, comfort

PVA = patient-ventilator assessment

importance and priority. Major themes were noted, and questions were consolidated where possible into a manageable workflow. The themes that emerged were safety, artificial airway assessment, resource allocation, and patient-oriented outcomes. Four population, intervention, comparators, and outcomes (PICO) questions were selected from these themes. After discussion and refinement of the PICO questions, outcomes were narrowed to ventilator-free days (VFDs), patient safety, and mortality. Agreement was used to assess interrater variability among committee members.[7] The protocol for this systematic review was registered on PROSPERO (CRD42022384688). Details of the PICO questions considered here are shown in Table 1.

Literature Review, Study Selection, and Data Analysis

The librarian created search strategies based on target articles and keywords limited to publications in the English language. The databases searched were PubMed/MEDLINE, the Cochrane Database of Systematic Reviews, Embase, and CINAHL. The last update was performed on July 14, 2023 (see related supplementary materials at http://www.rcjournal.com). The returned references were screened for inclusion in Rayyan (https://rayyan.ai *Accessed June 12, 2024*). Inclusion criteria included all age groups and from all countries, randomized controlled trials (RCTs), systematic reviews, observational studies, and the English language. Exclusion criteria included non-ventilated subjects, animal studies, narrative reviews, case series, retrospective cohort studies, and laboratory studies (see related supplementary materials at http://www.rcjournal.com). For each PICO question, at least 2 RTs screened studies in Rayyan; and once the initial screening was completed, the references were moved to EndNote (Clarivate, Philadelphia, Pennsylvania) to resolve conflicts and to manage full-text articles. Conflicts were resolved via discussion among panel members or by a third member of

Table 2. Parameters to Be Monitored to Ensure Lung-Protective Ventilation

Parameter	Population	Practice
V_T	All	Assess expired V_T
		Target 4–8mL/kg/PBW
		Adjust if outside range
P_{plat}	All	Assess P_{plat}
		Limit to ≤ 30 cm H_2O (adult)
		Limit to ≤ 28 cm H_2O (pediatric)
		Adjust settings if elevated
PEEP	All	Assess PEEP and auto-PEEP
		Regardless of the approach used for PEEP selection, use higher PEEP in adults with moderate and severe ARDS and lower PEEP with mild ARDS.
		Use ARDSNet PEEP:F_{IO_2} table in children with ARDS
		No specific PEEP target in those without ARDS
		Adjust settings if auto-PEEP is present
Driving pressure	All	Assess driving pressure
		Target ≤ 15 cm H_2O
		Adjust settings if elevated
F_{IO_2}	All	Assess oxygenation and F_{IO_2}
		Avoid hypoxemia and hyperoxemia
		Adjust F_{IO_2} as needed
Other settings	All	Evaluate and adjust to achieve clinical goals

V_T = tidal volume
PBW = predicted body weight
P_{plat} = plateau pressure
ARDSNet = ARDS Network

the panel. Data were extracted and entered into an Excel spreadsheet (Microsoft, Redmond, Washington) for review by the full committee.

Development of Clinical Practice Guidelines

For each PICO question, the committee developed recommendations based on the Grading of Recommendations, Assessment, Development, and Evaluation (GRADE) methodology (https://gdt.gradepro.org/app/handbook/handbook.html *Accessed June 10, 2024*).[8] Recommendations for each PICO question considered the quality of evidence, a balance of desirable and undesirable effects, assumptions of patient values and preferences, use of resources, health equity, acceptability of an intervention, and the feasibility of implementation. The certainty of effect estimates for each outcome were then categorized as high, moderate, low, or very low according to the GRADE process. Evidence tables were created to assess the quality of the evidence (see related supplementary materials at http://www.rcjournal.com). The committee discussed recommendations and their strength until agreement on the final wording and rationale with qualifications for each PICO question was reached. Recommendations were designated as strong or conditional, and the terminology "we recommend" was used for strong recommendations and "we suggest" for conditional recommendations. Further descriptions and details of the methodology used can be found in the online supplementary materials.

PICO 1

Does the assessment of lung-protective ventilation reduce mortality?

Background. During mechanical ventilation, selecting and monitoring various parameters, including the mode, breathing frequency, tidal volume (V_T), P_{plat}, inspiratory pressure, PEEP, breath cycling criteria, and F_{IO_2}, is required.[9] The concept of lung-protective ventilation is an umbrella term that includes targeting physiologic V_T based on predicted body weight, limiting the end-inspiratory P_{plat} to ≤ 30 cm H_2O, appropriate PEEP, limiting driving pressure, and detecting excessive patient effort (Table 2). Physiologic V_T in humans is 4–8 mL/kg/predicted body weight. The ARDS Network (ARDSNet) reported a significant reduction in mortality (9% absolute reduction) in adults with ARDS when targeting 6 mL/kg/predicted body weight (P_{plat} ≤ 30 cm H_2O) compared to 12 mL/kg/predicted body weight (P_{plat} ≤ 50 cm H_2O).[9] The use of PEEP in various disease states is controversial; however, appropriate PEEP should be set to avoid the opening and closing of alveoli during the respiratory cycle (atelectrauma) without contributing to alveolar overdistention.[10]

Summary of the Evidence. *Lung-protective ventilation in patients without ARDS.* Serpa-Neto et al[10] conducted a meta-analysis of adult subjects enrolled among 20 RCTs (n = 2,822) to compare lower versus higher V_T. Their analysis found that lower V_T resulted in lower mortality (6.5% vs 10.7%; relative risk 0.64 [95% CI 0.46–0.86]) and was associated with a reduction in the development of lung injury (relative risk 0.33 [95% CI 0.23–0.47]) but did not shorten the duration of mechanical ventilation (standardized mean difference 0.48 [95% CI −0.53 to 1.27] d). Also, lower V_T was associated with improvements in pulmonary infections, atelectasis, and hospital length of stay (LOS). There were no differences in gas exchange or oxygenation as measured by the P_{aO_2}/F_{IO_2}. A systematic review and meta-analysis by De Monnin et al[11] of lower versus higher V_T in emergency departments included 11 studies of 12,912 adult subjects. Lower V_T was associated with decreased mortality (odds ratio 0.80 [95% CI 0.72–0.88]), decreased hospital LOS (mean difference −1.0 [95% CI −2.3 to −0.1] d), increased VFDs (1.4 [95% CI 0.4–2.4] d), decreased development of ARDS, and

shorter ICU LOS (mean difference −1.0 [95% CI −1.7 to −0.3] d). No studies evaluating V_T in children without ARDS and no studies evaluating V_T in neonates without respiratory distress syndrome were found.

Lung-protective ventilation in patients with ARDS. Petrucci and De Feo[12] conducted a systematic review and meta-analysis of 1,297 adult subjects enrolled in 6 RCTs. Lower (< 7 mL/kg) versus higher V_T (10–15 mL/kg) reduced hospital mortality (relative risk 0.80 [95% CI 0.69–0.92]), no difference in weighted mean difference (WMD) for duration of mechanical ventilation (WMD −0.83 [95% CI −1.92 to 0.27] d), and no difference in mortality when P_{plat} was kept ≤ 31 cm H_2O (relative risk 0.80 [95% CI 0.88–0.92]). Walkey et al[13] performed a network meta-analysis and found a decrease in mortality for lower V_T (relative risk 0.80 [95% CI 0.66–0.98]). However, this was not statistically significant when open lung trials were excluded (relative risk 0.87 [95% CI 0.70–1.08]), and the authors did not evaluate the duration of mechanical ventilation or other secondary outcomes.

The Pediatric Acute Lung Injury Consensus Conference (PALICC) guideline[14] suggested physiologic V_T (6–8 mL/kg) in children with ARDS with a conditional recommendation (very low certainty). No RCTs in children with ARDS were noted; therefore, outcomes are unclear. No identified studies evaluating V_T in neonates with ARDS or respiratory distress syndrome were found.

PEEP in Patients With ARDS. Dianti et al[15] conducted a network meta-analysis of 4,646 adult subjects enrolled in 18 RCTs and found that higher levels (vs lower levels) of PEEP were associated with a lower mortality rate in adults with moderate to severe ARDS. A high certainty for a benefit for higher PEEP without recruitment maneuvers was associated with lower mortality (relative risk 0.77 [95% CI 0.60–0.96]). In a systematic review and meta-analysis, Briel et al[9] reported that in subjects with moderate to severe ARDS (n = 1,892) mortality was 34.1% in the higher PEEP group and 39.1% in the lower PEEP group (adjusted relative risk 0.90 [95% CI 0.81–1.00]). In subjects with mild ARDS (n = 404), mortality was 27.2% in the higher PEEP group and 19.4% in the lower PEEP group (adjusted relative risk 1.37 [95% CI 0.98–1.92]). The groups did not differ in rates of pneumothorax, hospital deaths following pneumothorax, use of vasopressors, or number of days with unassisted breathing during the first 28 d of the study. The European ARDS guidelines, updated in 2023, were unable to make a recommendation for or against higher versus lower PEEP to reduce mortality in patients with ARDS.[16]

It is also important to assess auto-PEEP (intrinsic PEEP, occult PEEP). Auto-PEEP is particularly problematic in patients with obstructive lung disease, where its presence contributes to dynamic hyperinflation, leading to alveolar overdistention, hemodynamic compromise, and resulting in an increased trigger threshold.[17,18] Auto-PEEP can also result in decreased venous return and hemodynamic compromise.

PEEP in Children With ARDS. No RCTs or systematic reviews were found. However, Khemani et al[19] evaluated databases from multiple centers regarding PEEP in children with ARDS (n = 1,134). Those who were managed with PEEP lower than the recommended level from the ARDSNet PEEP:F_{IO_2} table had increased mortality (odds ratio 2.05 [95% CI 1.24–3.22]) and fewer VFDs (15.6 [95% CI 0–21.2] d vs 17.4 [95% CI 3.0–22.1] d). The PALICC guidelines recommend that PEEP be titrated to oxygenation, hemodynamics, and compliance measurements and suggest maintaining PEEP at or above the level recommended by the ARDSNet protocol. No studies evaluating PEEP in neonates were found.

Driving Pressure. Driving pressure is the difference between P_{plat} and total PEEP. Amato et al[20] reviewed data from 3,562 adult subjects with ARDS enrolled in RCTs to evaluate the impact of day 1 driving pressures on mortality. Driving pressure was significantly associated with mortality (relative risk 1.41 [95% CI 1.31–1.51]), and neither the V_T (relative risk 1.02 [95% CI 0.95–1.10]) nor PEEP (relative risk 1.03 [95% CI 0.95–1.11]) was associated with mortality. A systematic review and meta-analysis[21] confirmed these results (relative risk 1.44 [95% CI 1.11–1.88]) across 7 studies (5 secondary analyses and 2 observational studies). Costa et al[22] assessed driving pressure, V_T, breathing frequency (f), and mortality in 4 systematic reviews and meta-analyses with 4,549 subjects and found that all 3 parameters were associated with mortality. The effect size for each cm H_2O increase in driving pressure was about 4 times greater than that of each 1 breath/min increase in f, leading to higher mortality. In children, the PALICC guidelines recommended that driving pressure be limited to < 15 cm H_2O.[23] No studies evaluating driving pressure were found in neonates.

F_{IO_2}. In 2022, an AARC CPG recommended an S_{pO_2} range of 94–98% for general critically ill patients and an S_{pO_2} range of 88–93% for patients with ARDS, especially when the F_{IO_2} is > 0.7.[24] Cumpstey et al,[25] in a systematic review and meta-analysis, found that normoxemia versus hyperoxemia was associated with decreased mortality, (odds ratio 0.73 [95% CI 0.57–0.97]). In children, the PALICC guidelines recommend an S_{pO_2} range of 92–97% with mild or moderate ARDS, and an S_{pO_2} < 92% can be accepted in children with severe ARDS.[23] However, an ungraded good practice statement states to avoid hypoxemia (S_{pO_2} < 88%) or hyperoxemia (S_{pO_2} > 97%) in mechanically ventilated children.[14] There were no recommendations in the AARC pediatric oxygen therapy CPG regarding F_{IO_2}.[26] No studies were found evaluating F_{IO_2} in neonates. Furthermore, no studies evaluating f, inspiratory-expiratory (I-E) ratio, inspiratory flow, and inspiratory time were found.

Although we did not identify any evidence directly evaluating whether the assessment of lung-protective ventilation improves outcomes, it is reasonable to adopt mechanical ventilation practices shown to reduce the risks of mortality and complications. Therefore, assessments of patients receiving mechanical ventilation should focus on lung-protective ventilation.

Recommendations

1. We recommend the assessment of P_{plat} to ensure lung-protective ventilator settings (strong recommendation, high certainty).
2. We recommend an assessment of V_T to ensure lung-protective ventilation (4–8 mL/kg/predicted body weight) (strong recommendation, high certainty).
3. We recommend documenting V_T as mL/kg predicted body weight (strong recommendation, high certainty).
4. We recommend an assessment of PEEP and auto-PEEP (strong recommendation, high certainty).
5. We suggest assessing driving pressure to prevent ventilator-induced injury (conditional recommendation, low certainty).
6. We suggest assessing F_{IO_2} to ensure normoxemia (conditional recommendation, very low certainty).

Justification and Implementation Considerations. Implementation of lung-protective ventilation is a priority due to the important benefits for all patients (Table 2). Each PVA should evaluate V_T, P_{plat}, PEEP, auto-PEEP, driving pressure, F_{IO_2}, and other parameters. Parameters should be documented in the medical record as well as any changes resulting from the assessment. V_T should be documented in mL/kg/predicted body weight in addition to the absolute volume. Hospital quality assurance initiatives should track adherence to lung-protective practices and empower bedside clinicians to adjust ventilator settings using non-physician–directed protocols.

Note that we do not make recommendations regarding the long list of ventilator settings commonly included in a traditional ventilator check. In the United States, many of these are captured automatically and placed into the electronic medical record. As best practice, hospitals should continue to capture these settings in the medical record such as, but not necessarily limited to, mode, f, inspiratory time, I-E, peak inspiratory pressure, trigger sensitivity, alarm settings, and others. Each hospital needs to determine which ventilator settings and monitored values should be included. This is determined by the specific ventilator brands that are used and local culture. Our goal in this CPG is not to create an exhaustive list of what settings should be documented (ventilator check) but rather to focus on PVA to ensure lung-protective ventilation.

Future Research Opportunities. Future research opportunities include incorporating additional technology such as electrical impedance tomography, esophageal manometry, electrical activity of the diaphragm, and lung ultrasound into PVAs to assess their impact.[27-33] Lung- and diaphragm-protective ventilation, mechanical power, and excessive inspiratory effort (patient self-induced lung injury) are also important areas to evaluate for their potential impact on patient outcomes.[22,30,34-37]

PICO 2

Does remote (telehealth) PVA versus bedside assessment result in similar outcomes?

Background. Telemedicine is the use of medical information exchanged from one site to another via communications to access a patient's clinical health status.[38] In 2021, it was estimated that approximately 15% of intensive care beds in the United States were monitored by telemedicine programs.[39] In 2016, the European Respiratory Society (ERS) addressed telemonitoring of ventilator-dependent patients due to the paucity of high-level evidence and lack of confidence from a reliance on anecdotes.[40] The ERS adopted terminology and definitions and discussed legal issues associated with telemonitoring and other ethical and technical standards for consideration before implementation of telemonitoring. Telemedicine is traditionally staffed by physicians, advanced practice providers, nurses, and pharmacists. Telerespiratory services in the United States are expanding to provide remote set-up and adherence monitoring for CPAP in patients with obstructive sleep apnea, NIV follow-up in the home; and support for in-patient care teams in critical access facilities and skilled nursing facilities. A recent study included RTs in a telecritical care service and found that a telemedicine RT service can support bedside RTs, effectively monitor best practice bundles, and assist RTs with PVAs.[41] Despite the potential benefits that a telerespiratory service might provide, their benefits in terms of patient outcomes and cost savings are yet to be evaluated.

Summary of the Evidence. We identified 4 studies (Table 3), with 2 related to home mechanical ventilation. Pinto et al[42] included 40 subjects with amyotrophic lateral sclerosis receiving NIV in which adherence and ventilator parameters were assessed during office visits in the control group, and the intervention group received a modem device connected to the ventilator in their home. Subjects were randomly assigned to one of 2 groups according to their residential area. Findings indicated that changes to NIV settings decreased ($P < .001$); office visits decreased from an incidence density of 9.01 to 3.02 in the intervention group ($P < .001$); emergency department visits ($P < .001$) and hospital admissions were lower ($P < .001$), and there was no difference in mortality ($P = .13$). Bertini et al[43] included

Table 3. Summary of Evidence for Population, Intervention, Comparators, and Outcomes Question 2, Does Remote (Telehealth) Patient-Ventilator Assessment Versus Being at the Bedside Result in Similar Outcomes?

Study	Design	Setting	Subjects	Outcomes	Major Findings
Pinto et al 2010[42]	Prospective, single-blinded trial; assigned according to residence near or distant from the clinic.	Home NIV for individuals with ALS.	The control group in which adherence and ventilator parameter settings were assessed during office visits or the intervention group with a modem connected to the ventilator.	No difference in adherence between groups. Changes in ventilator settings were lower in the telemedicine group but increased during the initial period. Office or emergency visits and in-hospital admissions were significantly lower in the telemedicine group.	Telemonitoring reduced health care utilization in subjects receiving NIV at home.
Bertini et al 2012[43]	2-y observational study.	Home mechanical ventilation.	16 subjects ventilated for at least 1 y and for ≥ 8 h/d.	Adherence was good in 56% and poor in 44% of subjects. Emergency visits were avoided in 63% of cases. The satisfaction scores were higher in adherent versus non-adherent subjects.	The telemonitoring system was feasible and effective in more adherent subjects, who claimed a high rate of satisfaction.
Bell et al 2016[44]	RTs were randomized to perform face-to-face assessments or telemedicine assessments.	Mechanically ventilated subjects; 5 in neonatal ICU and 6 in pediatric ICU.	16 RTs with subspecialty experience caring for ventilated neonates and children in the ICU.	Agreement of 14 ventilator-derived and patient-based respiratory variables of a typical mechanically ventilated patient assessment.	Telemedicine evaluations agreed well with face-to-face for 10 of 14 aspects. Poor correlation was noted for more complex, patient-generated parameters.
Pierce et al 2022[41]	Observational report of 1 mo.	Tele-ICU service during COVID covering 320 adult ICU beds in an academic medical center; parallel service to bedside RTs.	7 RTs	Primary: number of interventions taken by tele-ICU RT instead of bedside RT. Secondary: the amount of PPE saved due to substituting traditional RT service with eRT.	Over 1,500 interventions resulted in avoiding several near-miss events. Benefits such as improved protocol-driven patient care, elevated health care system performance, and lower expense.

NIV = noninvasive ventilation
ALS = amyotrophic lateral sclerosis
RTs = respiratory therapists
Tele-ICU = telemedicine ICU
PPE = personal protective equipment
eRT = telemedicine respiratory therapist

16 subjects receiving mechanical ventilation ≥ 8 h/d for at least 1 y. This pilot study was to test telemonitoring in the home when supervised by a physician in an ICU versus scheduled office visit every 2 months. Telemonitoring was feasible and effective in adherence, subject satisfaction ($P = .02$), decreased emergency department visits, and health care utilization.[42,43] The other 2 studies, from acute care centers, related to invasive mechanical ventilation. Bell et al[44] included neonatal and pediatric critical care subjects. RTs were randomized to telemonitoring or bedside assessment. The agreement among RTs assessing the assessment was measured and found that telemedicine was less effective for

Table 4. Outcomes for Heat-and-Moisture Exchangers Versus Heated Humidification (Intervention: Heat-and-Moisture Exchanger; Comparison: Heated Humidifier)

Outcome	Relative Effect (95% CI)	Subjects, *n* (studies, no.)	Certainty of Evidence (GRADE)
Artificial airway occlusion	RR 1.59 (0.60–4.19)	2,171 (15)	Low
Pneumonia	RR 0.93 (0.73–1.19)	2,251 (13)	Low
All-cause mortality	RR 1.03 (0.89–1.20)	1,951 (12)	Low

Data are presented as relative risk (95% CI).
GRADE = Grading of Recommendations, Assessment, Development, and Evaluation
RR = relative risk
From Reference 49.

more complex evaluations (kappa = −0.25 [95% CI −0.46 to −0.04]). Pierce et al,[41] in an observational study during COVID-19, with 1,500 interventions (average assessment time of 6.1 ± 3.8 min), found that RTs providing tele-ICU from a remote location within the hospital setting improved protocol-driven subject care, elevated health care system performance, and implied lower expenses. Given the current evidence, it is difficult to determine if similar outcomes are found between traditional PVAs and respiratory telehealth PVAs.

Recommendations

1. In noninvasively and invasively mechanically ventilated patients, we suggest the use of telemonitoring to supplement direct bedside assessment in settings of limited resources (conditional recommendation, low certainty).
2. In noninvasively and invasively mechanically ventilated patients, we suggest that direct bedside assessment rather than telemonitoring be used when resources are adequate (conditional recommendation, low certainty).

Justification and Implementation Considerations. Overall, the certainty of evidence from these studies is low. Studies were small in number of subjects, from a single hospital setting, and mostly observational. In the Bertini study,[43] allocations according to residence near or distant from the clinic introduced bias. The available evidence suggests a benefit for telemonitoring in settings of limited resources, such as what might occur in a rural setting, during a global pandemic, or in departments with critical staffing limitations. However, telemonitoring cannot be used for more complex assessments such as auscultation or cuff pressure measurements. It cannot be used for interventions such as suctioning the artificial airway or airway repositioning. These assessments are best addressed with a clinician at the bedside. Ventilator changes and manipulations, that is, P_{plat} or driving pressure measurements, may also be difficult to perform remotely. Reimbursement for respiratory telehealth should be addressed.

Future Research Opportunities. Current evidence does not support that telemonitoring is equivalent to direct bedside monitoring, and thus, it is not recommended when resources are adequate. However, the potential benefit of telerespiratory programs seems obvious in the setting of limited resources. It is important to determine the cost-effectiveness of respiratory telehealth programs. An understanding of the limitations of care delivered through respiratory telehealth services needs further investigation, and there is a need to identify the most effective collaboration models between respiratory telehealth providers and on-site health care providers. Furthermore, can technology be leveraged to improve telemonitoring? And is there a potential for harm? Research in this area is essential.

PICO 3

Does assessing patients receiving mechanical ventilation for adequate humidity improve patient outcomes?

Background. Ensuring adequate airway humidification for patients receiving either NIV or invasive mechanical ventilation is essential to maintain patient safety. When the normal warming and humidification function of the upper airway is bypassed with an artificial airway, the inspired gas must be warmed and humidified before delivery to the patient.[45] Whereas NIV does not bypass the upper airway, inadequate humidification of the inspired gas can lead to intolerance,[46] which may lead to NIV failure.[47] Commonly reported adverse outcomes associated with inadequate humidification during mechanical ventilation include ventilator-associated pneumonia (VAP), mucus plugging and airway occlusion, and mortality.[48,49] Thus, the PVA must include assessing parameters associated with adequate humidification.

Summary of the Evidence. No studies were identified that directly compared assessment of adequate humidification versus not in mechanically ventilated subjects. Instead, the literature focused on comparing outcomes for various methods of humidification. A systematic review[49] of studies comparing heated humidifiers (HHs) versus heat-and-

moisture exchangers (HMEs) sought to determine which device was more effective at preventing airway occlusion, VAP, and mortality. A total of 34 trials were included, resulting in the evaluation of data from 2,828 subjects receiving invasive mechanical ventilation. Three of the included studies reported data for pediatric subjects. There was no difference between HHs and HMEs for any of the outcomes (Table 4). We found no RCTs published after 2017. An observational pre-post HME utilization study published in 2012 also reported no difference in VAP, duration of mechanical ventilation, or ICU LOS between HH and HME.[48]

We did not identify any studies meeting our inclusion criteria for NIV. However, a 2012 narrative review states that appropriate humidification must be provided during NIV and states that there may be some benefit to utilizing HHs to ensure adequate humidification, especially in the acute care setting.[47]

Recommendations

1. We suggest assessing adequate humidification for patients receiving NIV and invasive mechanical ventilation (conditional recommendation, very low certainty).
2. We suggest assessing the appropriateness of the humidification device during NIV and invasive mechanical ventilation (conditional recommendation, low certainty).

Justification and Implementation Considerations. Best practice regarding the need to assess the adequacy of humidification for patients receiving mechanical ventilation may be self-evident. Nonetheless, inadequate humidification has significant adverse patient outcomes; and humidification status must be evaluated, adjusted, modified, and documented during a PVA. Bedside assessment of adequate humidification is challenging. Several parameters have been suggested including condensation at the proximal airway, suctioning frequency, secretion volume and consistency, mucus plugging and endotracheal tube (ETT) occlusion, and increases in airway resistance.[45,46,50]

Whereas we noted that HHs or HMEs have similar outcomes, HME performance varies widely, specifically related to humidity output. Absolute humidity delivery from an HME should be > 30 mg H_2O/L.[47,51] In a bench study of 48 different HMEs, Lellouche et al[51] reported that independent assessments of HME humidity output were consistently lower than manufacturer reports and that approximately 25% of devices had humidity outputs less than acceptable. Clinicians must understand that not all HMEs provide adequate humidification. It is also recognized that there are some contraindications and cautions for HME that should be considered when selecting a method of humidification during mechanical ventilation. Considerations include quantity and quality of secretions, additional dead space when employing a lung-protective ventilation strategy, body temperature, presence of leaks, impact on airway resistance, and patient comfort.[46]

Future Research Opportunities. Important questions remain regarding the frequency of assessment of humidification and the measures of adequate humidification that best predict undesirable patient outcomes. Inspired airway temperature, commonly monitored during mechanical ventilation, is not a surrogate for adequate humidification. Unfortunately, there currently does not exist a practical means to measure relative or absolute humidity delivered during mechanical ventilation; and therefore, we cannot directly address this PICO question.

PICO 4

Does assessing the artificial airway/interface prevent complications?

Background. In adults receiving invasive or noninvasive mechanical ventilation, fundamental components of artificial airway assessment during a PVA include assessment of the artificial airway or the interface for NIV. Clinicians should assess endotracheal/tracheostomy tube size, whether it is in the correct position, and whether it is adequately secured. Clinicians should also assess airway patency, cuff pressure, and skin integrity around the securement device. Skin pressure injury caused by artificial airways is common in the ICU, with an estimated 5.5% attributed to tracheostomy tubes.[52] Complications related to the tracheostomy tube include the impairment of neck tissue, scarring around the incision site, tracheal stenosis, and impairment in speech and swallowing. ETTs and tube holders contribute to injury at the mouth, lips, and cheeks, which negatively impacts the quality of life, increases the LOS, and risks an increase in mortality.

Skin injury with NIV interfaces occurs due to repeated friction and contact forces of interfaces against soft facial tissue and/or prominences within a moist environment.[53] For example, an NIV mask impairs facial tissue across the nose and can cause permanent harm to the patient. Therefore, the interface should be assessed for appropriate fit, any pressure points, and comfort during each PVA. Given the conspicuous location of these injuries, the impact they can have on quality of life and lack of reimbursement requires attentiveness and diligence. Most pressure injuries or iatrogenic injuries $>$ stage 3 no longer qualify for reimbursement through the Centers for Medicare and Medicaid Services. Clinicians conducting a thorough PVA are providing value-based patient-centric care, and prevention is, therefore, essential to eliminate patient complications and added cost to the organization.[52]

Another key element of artificial airway assessment is cuff pressure. There is concern that insufficient cuff inflation (low cuff pressure) can result in microaspiration of oral secretions and increase the risk of VAP. The shape of the cuff and the cuff material have also been engineered to reduce VAP. Conversely, overinflation of the cuff can impede capillary blood flow and lead to tracheal injury. Appropriate cuff pressure to reduce microaspiration and tracheal injury has been identified as 20–30 cm H_2O.[54,55] Consensus on how to measure cuff pressure and with what frequency has yet to be established.

Summary of the Evidence. *Prevention of pressure injury.* Moser et al[52] conducted a systematic review and meta-analysis of 10 studies enrolling 2,023 subjects and evaluated interventions that reduced the incidence of tracheostomy-related injury. When compared with gauze or no dressing, utilization of dressings with hydrophilic properties decreased incidence by > half (relative risk 0.45 [95% CI 0.28–0.70], $P = .001$). Other interventions, such as hydrocolloid dressings, hook-and-loop-style securement collars, and extended-length tracheostomy tubes, were noted to also reduce injury. However, several interventions were components of a bundled-care approach, so the sensitivity of individual interventions was difficult to assess. Cumulatively, bundled interventions reduced the incidence of tracheostomy-related pressure injuries from 17.0% to 3.5% ($P < .001$).[52]

To assess the reduction in skin injury associated with NIV interfaces, Orlov and colleagues[53] used computerized modeling and demonstrated higher protective performance with foam-based dressings than hydrocolloid dressing. Brill[56] discussed the variety of interfaces commercially available and the need to assess facial anatomy to determine the best fit to avoid skin injury and potentially alternating interface type/size to relieve pressure points. Furthermore, NIV interface manufacturers need to consider skin and patient comfort in their designs.

Cuffs and Cuff Pressures. Maertens and colleagues[57] evaluated the effect of cuff shape on ventilator-associated events (VAEs). They reviewed 6 RCTs with a primary outcome of hospital-acquired pneumonia and secondary outcomes of mortality, duration of mechanical ventilation, hospital LOS, ICU LOS, and cuff underinflation. No significant difference in hospital-acquired pneumonia was reported between the tapered cuff and standard cuff shape (odds ratio 0.97 [95% CI 0.73–1.28], $P = .81$). The authors noted that the evaluation of tapered cuffs as part of a bundle with appropriate other measures to reduce VAP had not yet been studied.

Letvin et al[54] evaluated infrequent (after intubation and then only when indicated) versus frequent (after intubation, every 8 h, and when indicated) measuring of cuff pressures. The primary outcome was VAEs. The authors reported a similar VAE occurrence in the infrequent and frequent groups (5.8% vs 3.6%, $P = .37$). Interestingly, there was a large difference in the number of measurements between the 2 groups: 336 for the infrequent group and 1,531 for the frequent group. The authors concluded that the increase in work load and resource allocation in frequent cuff pressure monitoring did not impact VAE.[54]

Another practice that varies is how to measure cuff pressure. Some rely on palpation of the fullness of the pilot balloon, minimal occlusive volume, or minimal leak technique.[58] These are inaccurate when compared to analog or digital pressure manometers.[59] In recent years, devices that measure cuff pressures continuously have been evaluated in RCTs. Valencia et al[60] randomized 142 subjects to either continuous regulation of cuff pressure ($n = 73$) or cuff pressure measurements every 8 h ($n = 69$). Dat and colleagues[61] randomized 597 subjects to receive cuff pressure monitoring by manometer or by continuous device. Marjanovic and colleagues[62] randomized 434 subjects with trauma to either continuous cuff pressure measuring device ($n = 216$) or measurements every 8 h ($n = 218$). The results of these 3 RCTs were similar. All reported no reduction in the rate of VAP, intervention 22% versus control 29% ($P = .44$),[60] intervention 25% versus control 23% ($P = .53$),[61] and intervention 33.8% versus control 29.4% ($P = .71$).[62] Furthermore, there was no benefit for continuous cuff pressure monitoring for microbiologically confirmed VAP, distribution of early or late onset VAP, causative microorganisms, the proportion of intubated days without antimicrobials, rate of ICU discharge, cost of ICU LOS, cost of ICU antimicrobials, cost of hospital LOS, ICU mortality, or hospital mortality.[60,61]

Preventive bundles are often employed in ICUs to decrease the incidence of VAP. In addition to cuff pressure monitoring, bundles often include elevation of the head of the bed, routine oral care, and protocols to identify extubation readiness. Recommendations by The Society for Healthcare Epidemiology[63] agree with those outlined here. We found a lack of evidence in terms of patient-important outcomes for the use of tapered airway cuffs, frequent cuff pressure monitoring, and devices that automatically adjust cuff pressure. Evidence is also lacking for tube positioning and securing artificial airways.

Recommendations

1. We recommend that the skin surrounding artificial airways and NIV interfaces be assessed (strong recommendation, high certainty).
2. We suggest assessing the dressing used for tracheostomy tubes and NIV interfaces (conditional recommendation, low certainty).
3. We recommend assessing the pressure inside the cuff of artificial airways using a manometer (strong recommendation, high certainty).

4. We recommend that continuous cuff pressure assessment should not be implemented to decrease the risk of VAP (strong recommendation, high certainty).
5. We suggest assessing proper placement and securement of artificial airways (conditional recommendation, very low certainty).

Justification and Implementation Considerations. For patient safety and comfort, skin integrity must be assessed as part of the PVA. This is important not only for patients receiving NIV but also for patients with artificial airways. In the United States, this also has implications for reimbursement.

The area with the most convincing evidence relates to the artificial airway cuff. There exists high levels of evidence related to the type of cuff and management of cuff pressure. This relates to the prevention of tracheal injury and risk for VAP and VAE. The cuff type, cuff material, and frequency of cuff pressure measurement might not be as important as once thought. But it should also be appreciated that cuff pressure is also important in the context of tracheal injury. The frequency of cuff pressure measurements is unclear and might best be determined by local culture and resources.

Although the certainty of evidence is very low and prevents us from directly answering the PICO question, we suggest assessing tube position and ensuring that the airway is secure. It is universal practice to ensure that the tube is not placed into a main bronchus and that the cuff is not in the larynx or pharynx. It is also accepted that the tube be properly secured to prevent accidental extubation. Note that we do not make a recommendation regarding the securement method, which is determined by local practice.

Future Research Opportunities. There are aspects of assessing skin integrity related to artificial airways and NIV interfaces that currently lack evidence with high certainty. Questions persist around best practices, such as optimal skin pressure injury prevention products and optimal timing for rotation of NIV interfaces. The role of cuff design and frequency of cuff pressure measurements must be established.

Discussion

Effectiveness and safety are important considerations in mechanically ventilated patients. These 4 PICO questions are specific to issues related to the PVA. In North America, this is of particular interest to RTs, as they are the bedside clinicians who most commonly perform the PVA. Regardless of the health care delivery model, an individual with expertise in respiratory care should perform the PVA. Our recommendations necessitate a thorough assessment of important parameters known to affect patient outcomes. This includes an assessment of the patient and evaluation of ventilator settings; assuring lung-protective strategies; the use of direct bedside assessment when resources are adequate or to supplement assessment with telemedicine with limited resources; assessment for adequate humidification in patients receiving NIV and invasive mechanical ventilation; the evaluation and prevention of skin injury; and for artificial airways, cuff pressure monitoring, and ETT tube placement and securement.

A common question asked is "How often should a PVA be performed?" This CPG does not address that question. Evidence is lacking to provide guidance. Moreover, the frequency of PVA is determined by patient acuity, available resources, and institutional preferences. For instance, a mechanically ventilated patient in a long-term post-acute care setting with stable settings may require less frequent PVAs as compared to an unstable patient emergently intubated due to respiratory failure. The frequency of PVA is not established by statute or CPGs. But is there potential for harm if a clinician such as an RT is tasked with PVAs more frequently than necessary? Might this result in clinical oversight if the RT or other clinician focuses on completing the task rather than performing a thorough assessment? These important questions must be addressed locally and cannot be stipulated in an evidence-based CPG.

The traditional patient-ventilator system check is ventilator-centric and addresses parameters mostly related to the ventilator rather than from a patient-centric focus. The PVA aims to guide the ventilator management to achieve best patient outcomes rather than the frequency of documenting ventilator settings. Thus, the PVA is tailored to the individual patient's needs. This CPG stresses patient assessment and patient response to mechanical ventilation. This CPG does not recommend which ventilator settings and monitored values are to be documented in the medical record, as this should be determined locally.

There is absence of high-quality evidence to support some of our recommendations. Questions remain about which parameters of the PVA are essential for protective lung ventilation and patient safety. How can telehealth be best used when resources are insufficient? How does one select the use of HH or HME? What is the best strategy to maintain skin integrity related to the interface and cuff pressures? Many opportunities exist for quality improvement projects related to implementing PVAs.

Summary

This CPG provides guidance in 4 areas related to PVA: lung-protective ventilation, use of telemedicine, adequacy of airway humidification, and artificial airway/interface assessment. The recommendations are offered to assist bedside clinicians in the care of patients receiving invasive mechanical ventilation and NIV. The focus of the PVA should be patient-centric rather than focused on the ventilator, which requires a skilled clinician to make the proper

assessment, interpret the findings relative to the individual patient, and then adjust the ventilator to meet the patient's needs.

REFERENCES

1. Branson RD. Monitoring ventilator function. Crit Care Clin 1995;11 (1):127-143.
2. AARC clinical practice guideline: patient-ventilator system check. Respir Care 1992;37(8):882-886.
3. Akhtar SR, Weaver J, Pierson DJ, Rubenfeld GD. Practice variation in respiratory therapy documentation during mechanical ventilation. Chest 2003;124(6):2275-2282.
4. Bellani G, Laffey J, Pham T, Fan E, Brochard L, Esteban A, et al; ESICM Trials Group. Epidemiology, patterns of care, and mortality for patients with acute respiratory distress syndrome in intensive care units in 50 countries. JAMA 2016;315(8):788-800.
5. Khemani RG, Smith L, Lopez-Fernandez Y, Kwok J, Morzov R, Klein M, et al; Pediatric Acute Respiratory Distress Syndrome Incidence and Epidemiology (PARDIE) Investigators; Pediatric Acute Lung Injury and Sepsis Investigators (PALISI) Network. Pediatric acute respiratory distress syndrome incidence and epidemiology (PARDIE): an international, observational study. Lancet Respir Med 2019;7(2):115-128.
6. Alqahtani JS, Mendes RG, Aldhahir A, Rowley D, AlAhmari MD, Ntoumenopoulos G, et al. Global current practices of ventilatory support management in COVID-19 patients: an international survey. J Multidiscip Healthc 2020;13:1635-1648.
7. Ranganathan P, Pramesh CS, Aggarwal R. Common pitfalls in statistical analysis: measures of agreement. Perspect Clin Res 2017;8(4):187-191.
8. Guyatt G, Oxman AD, Akl EA, Kunz R, Vist G, Brozek J, et al. GRADE guidelines: 1. Introduction-GRADE evidence profiles and summary of findings tables. J Clin Epidemiol 2011;64(4):383-394.
9. Briel M, Meade M, Mercat A, Brower RG, Talmor D, Walter SD, et al. Higher vs lower positive end-expiratory pressure in patients with acute lung injury and acute respiratory distress syndrome: systematic review and meta-analysis. JAMA 2010;303(9):865-873.
10. Serpa-Neto A, Cardoso S, Manetta J, Pereira V, Esposito D, Prado PAsqualucci M, et al. Association between use of lung-protective ventilation with lower tidal volumes and clinical outcomes among patients without acute respiratory distress syndrome: a meta-analysis. JAMA 2012;308(16):1651-1659.
11. De Monnin K, Terian E, Yaegar LH, Pappal RD, Mohr NM, Roberts BW, et al. Low tidal volume ventilation for emergency department patients: a systematic review and meta-analysis on practice patterns and clinical impact. Crit Care Med 2022;50(6):986-998.
12. Petrucci N, De Feo C. Lung-protective ventilation strategy for the acute respiratory distress syndrome. Cochrane Database Syst Rev 2013;2013(2):CD003844.
13. Walkey AJ, Goligher EC, Del Sorbo L, Hodgson CL, Adhikari NKJ, Wunsch H, et al. Low tidal volume versus non–volume-limited strategies for patients with acute respiratory distress syndrome. A systematic review and meta-analysis. Ann Am Thorac Soc 2017;14 (Supplement_4):S271-S279.
14. Fernandez A, Modesto V, Rimensberger PC, Korang SK, Iyer NP, Cheifetz IM; Second Pediatric Acute Lung Injury Consensus Conference (PALICC-2) of the Pediatric Acute Lung Injury and Sepsis Investigators (PALISI) Network. Invasive ventilatory support in patients with pediatric acute respiratory distress syndrome: from the Second Pediatric Acute Lung Injury Consensus Conference. Pediatr Crit Care Med 2023;24(12 Suppl 2):S61-S75.
15. Dianti J, Tisminetzky M, Ferreyro BL, Englesakis M, Del Sorbo L, Sud S, et al. Association of positive end-expiratory pressure and lung recruitment selection strategies with mortality in acute respiratory distress syndrome: a systematic review and network meta-analysis. Am J Respir Crit Care Med 2022;205(11):1300-1310.
16. Grasselli G, Calfee CS, Camporota L, Poole D, Amato MBP, Antonelli M, et al; European Society of Intensive Care Medicine Taskforce on ARDS. ESICM guidelines on acute respiratory distress syndrome: definition, phenotyping, and respiratory support strategies. Intensive Care Med 2023;49(7):727-759.
17. Hess DR. Respiratory care management of COPD exacerbations. Respir Care 2023;68(6):821-837.
18. Jubran A. Setting positive end-expiratory pressure in the severely obstructive patient. Curr Opin Crit Care 2024;30(1):89-96.
19. Khemani RG, Parvathaneni K, Yehya N, Bhalla AK, Thomas NJ, Newth CJL. Positive end-expiratory pressure lower than the ARDS Network protocol is associated with higher pediatric acute respiratory distress syndrome mortality. Am J Respir Crit Care Med 2018;198 (1):77-89.
20. Amato MB, Meade MO, Slutsky AS, Brochard L, Costa EL, Schoenfeld DA, et al. Driving pressure and survival in the acute respiratory distress syndrome. N Engl J Med 2015;372(8):747-755.
21. Aoyama H, Pettenuzzo T, Aoyama K, Pinto R, Englesakis M, Fan E. Association of driving pressure with mortality among ventilated patients with acute respiratory distress syndrome: a systematic review and meta-analysis. Crit Care Med 2018;46(2):300-306.
22. Costa ELV, Slutsky AS, Brochard LJ, Brower R, Serpa-Neto A, Cavalcanti AB, et al. Ventilatory variables and mechanical power in patients with acute respiratory distress syndrome. Am J Respir Crit Care Med 2021;204(3):303-311.
23. Emeriaud G, Lopez-Fernandez YM, Iyer NP, Bembea MM, Agulnik A, Barbaro RP, et al; Second Pediatric Acute Lung Injury Consensus Conference (PALICC-2) Group on behalf of the Pediatric Acute Lung Injury and Sepsis Investigators (PALISI) Network. Executive summary of the Second International Guidelines for the Diagnosis and Management of Pediatric Acute Respiratory Distress Syndrome (PALICC-2). Pediatr Crit Care Med 2023;24(2):143-168.
24. Piraino T, Madden M, Roberts KJ, Lamberti J, Ginier E, Strickland SL. AARC clinical practice guideline: management of adult patients with oxygen in the acute care setting. Respir Care 2022;67(1):115-128.
25. Cumpstey AF, Oldman AH, Martin DS, Smith A, Grocott MPW. Oxygen targets during mechanical ventilation in the ICU: a systematic review and meta-analysis. Crit Care Explor 2022;4(4):e0652.
26. Napolitano N, Berlinski A, Walsh BK, Ginier E, Strickland SL. AARC clinical practice guideline: management of pediatric patients with oxygen in the acute care setting. Respir Care 2021;66(7):1214-1223.
27. Beitler JR, Sarge T, Banner-Goodspeed V, Gong M, Cook D, Novack V, et al; EPVent-2 Study Group. Effect of titrating positive end-expiratory pressure (PEEP) with an esophageal pressure-guided strategy vs an empirical high PEEP- F_{IO_2} strategy on death and days free from mechanical ventilation among patients with acute respiratory distress syndrome: a randomized clinical trial. JAMA 2019;321(9):846-857.
28. Bhalla A, Baudin F, Takeuchi M, Cruces P; Second Pediatric Acute Lung Injury Consensus Conference of the Pediatric Acute Lung I, Sepsis Investigators N. Monitoring in pediatric acute respiratory distress syndrome: from the Second Pediatric Acute Lung Injury Consensus Conference. Pediatr Crit Care Med 2023;24(12 Suppl 2):S112-S123.
29. Florio G, Ferrari M, Bittner EA, De Santis Santiago R, Pirrone M, Fumagalli J, et al; investigators of the lung rescue team. A lung rescue team improves survival in obesity with acute respiratory distress syndrome. Crit Care 2020;24(1):4.
30. Goligher EC, Dres M, Patel BK, Sahetya SK, Beitler JR, Telias I, et al. Lung- and diaphragm-protective ventilation. Am J Respir Crit Care Med 2020;202(7):950-961.
31. Hadfield D, Rose L, Reid F, Cornelius V, Hart N, Finney C, et al. Neurally adjusted ventilatory assist versus pressure support ventilation:

a randomized controlled feasibility trial performed in patients at risk of prolonged mechanical ventilation. Crit Care 2020;24(1):220.
32. Karthika M, Wong D, Nair SG, Pillai LV, Mathew CS. Lung ultrasound: the emerging role of respiratory therapists. Respir Care 2019; 64(2):217-229.
33. Mojoli F, Bouhemad B, Mongodi S, Lichtenstein D. Lung ultrasound for critically ill patients. Am J Respir Crit Care Med 2019;199(6): 701-714.
34. de Vries HJ, Jonkman AH, de Grooth HJ, Duitman JW, Girbes ARJ, Ottenheijm CAC, et al. Lung- and diaphragm-protective ventilation by titrating inspiratory support to diaphragm effort: a randomized clinical trial. Crit Care Med 2022;50(2):192-203.
35. Dianti J, Matelski J, Tisminetzky M, Walkey AJ, Munshi L, Del Sorbo L, et al. Comparing the effects of tidal volume, driving pressure, and mechanical power on mortality in trials of lung-protective mechanical ventilation. Respir Care 2021;66(2):221-227.
36. Marini JJ, Gattinoni L, Rocco PR. Estimating the damaging power of high-stress ventilation. Respir Care 2020;65(7):1046-1052.
37. Pham T, Telias I, Beitler JR. Esophageal manometry. Respir Care 2020;65(6):772-792.
38. Davis TM, Barden C, Dean S, Gavish A, Goliash I, Goran S, et al. American Telemedicine Association guidelines for Tele-ICU operations. Telemed J E Health 2016;22(12):971-980.
39. Guinemer C, Boeker M, Furstenau D, Poncette AS, Weiss B, Morgeli R, et al. Telemedicine in intensive care units: scoping review. J Med Internet Res 2021;23(11):e32264.
40. Ambrosino N, Vitacca M, Dreher M, Isetta V, Montserrat JM, Tonia T, et al; ERS Tele-Monitoring of Ventilator-Dependent Patients Task Force. Telemonitoring of ventilator-dependent patients: a European Respiratory Society statement. Eur Respir J 2016;48(3):648-663.
41. Pierce M, Gudowski SW, Roberts KJ, Jackominic A, Zumstein KK, Shuttleworth A, et al. The rapid implementation of ad hoc tele-critical care respiratory therapy (eRT) service in the wake of the COVID-19 surge. J Clin Med 2022;11(3):718.
42. Pinto A, Almeida JP, Pinto S, Pereira J, Oliveira AG, de Carvalho M. Home telemonitoring of noninvasive ventilation decreases health care utilization in a prospective controlled trial of patients with amyotrophic lateral sclerosis. J Neurol Neurosurg Psychiatry 2010;81(11): 1238-1242.
43. Bertini S, Picariello M, Gorini M, Augustynen A, Villella G, Misuri G, et al. Telemonitoring in chronic ventilatory failure: a new model of surveillance, a pilot study. Monaldi Arch Chest Dis 2012;77(2):57-66.
44. Bell RC, Yager PH, Clark ME, Roumiantsev S, Venancio HL, Chipman DW, et al. Telemedicine versus face-to-face evaluations by respiratory therapists of mechanically ventilated neonates and children: a pilot study. Respir Care 2016;61(2):149-154.
45. Branson RD. Secretion management in the mechanically ventilated patient. Respir Care 2007;52(10):1328-1342.discussion 1342–1327.
46. Restrepo RD, Walsh BK; American Association for Respiratory Care. Humidification during invasive and noninvasive mechanical ventilation: 2012. Respir Care 2012;57(5):782-788.
47. Esquinas Rodriguez AM, Scala R, Soroksky A, BaHammam A, de Klerk A, Valipour A, et al. Clinical review: humidifiers during noninvasive ventilation–key topics and practical implications. Crit Care 2012;16(1):203.
48. Auxiliadora-Martins M, Menegueti MG, Nicolini EA, Alkmim-Teixeira GC, Bellissimo-Rodrigues F, Martins-Filho OA, et al. Effect of heat-and-moisture exchangers on the prevention of ventilator-associated pneumonia in critically ill patients. Braz J Med Biol Res 2012;45(12):1295-1300.
49. Gillies D, Todd DA, Foster JP, Batuwitage BT. Heat-and-moisture exchangers versus heated humidifiers for mechanically ventilated adults and children. Cochrane Database Syst Rev 2017;9(9):CD004711.
50. Branson RD, Gomaa D, Rodriquez D, Jr. Management of the artificial airway. Respir Care 2014;59(6):974-989.discussion 989–990.
51. Lellouche F, Taille S, Lefrancois F, Deye N, Maggiore SM, Jouvet P, et al; Groupe de travail sur les Respirateurs de l'AP-HP. Humidification performance of 48 passive airway humidifiers: comparison with manufacturer data. Chest 2009;135(2):276-286.
52. Moser CH, Peeler A, Long R, Schoneboom B, Budhathoki C, Pelosi PP, et al. Prevention of tracheostomy-related pressure injury: a systematic review and meta-analysis. Am J Crit Care 2022;31(6):499-507.
53. Orlov A, Gefen A. Differences in prophylactic performance across wound dressing types used to protect from device-related pressure ulcers caused by a continuous positive airway pressure mask. Int Wound J 2023;20(4):942-960.
54. Letvin A, Kremer P, Silver PC, Samih N, Reed-Watts P, Kollef MH. Frequent versus infrequent monitoring of endotracheal tube cuff pressures. Respir Care 2018;63(5):495-501.
55. Rello J, Sonora R, Jubert P, Artigas A, Rue M, Valles J. Pneumonia in intubated patients: role of respiratory airway care. Am J Respir Crit Care Med 1996;154(1):111-115.
56. Brill AK. How to avoid interface problems in acute noninvasive ventilation. Breathe 2014;10(3):230-242.
57. Maertens B, Blot K, Blot S. Prevention of ventilator-associated and early postoperative pneumonia through tapered endotracheal tube cuffs: a systematic review and meta-analysis of randomized controlled trials. Crit Care Med 2018;46(2):316-323.
58. Galinski M, Treoux V, Garrigue B, Lapostolle F, Borron SW, Adnet F. Intracuff pressures of endotracheal tubes in the management of airway emergencies: the need for pressure monitoring. Ann Emerg Med 2006;47(6):545-547.
59. Harvie DA, Darvall JN, Dodd M, De La Cruz A, Tacey M, D'Costa RL, et al. The minimal leak test technique for endotracheal cuff maintenance. Anaesth Intensive Care 2016;44(5):599-604.
60. Valencia M, Ferrer M, Farre R, Navajas D, Badia JR, Nicolas JM, et al. Automatic control of tracheal tube cuff pressure in ventilated patients in semi-recumbent position: a randomized trial. Crit Care Med 2007;35(6):1543-1549.
61. Dat VQ, Minh Yen L, Thi Loan H, Dinh Phu V, Thien Binh N, Geskus RB, et al. Effectiveness of continuous endotracheal cuff pressure control for the prevention of ventilator-associated respiratory infections: an open-label randomized controlled trial. Clin Infect Dis 2022;74(10):1795-1803.
62. Marjanovic N, Boisson M, Asehnoune K, Foucrier A, Lasocki S, Ichai C, et al; AGATE Study Group. Continuous pneumatic regulation of tracheal cuff pressure to decrease ventilator-associated pneumonia in trauma patients who were mechanically ventilated: the AGATE multicenter randomized controlled study. Chest 2021;160(2):499-508.
63. Klompas M, Branson R, Cawcutt K, Crist M, Eichenwald EC, Greene LR, et al. Strategies to prevent ventilator-associated pneumonia, ventilator-associated events, and non–ventilator hospital-acquired pneumonia in acute care hospitals: 2022 update. Infect Control Hosp Epidemiol 2022;43(6):687-713.