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RESEARCH ARTICLE

Kilickaya et al: STOP algorithm for mechanical ventilation

STOP algorithm for bedside mechanical ventilation: Standardized, evidence-based management of critically ill patients

Oguz Kilickaya[1#], Dimitrios Kantas[1#], Nirmala Manjappachar[1], Baiyong Wang[1], Marko Nemet[2], Rana Gur[1*], Yue Dong[2], Srdjan Gajic[3], Mirela Alic[4], Philippe R. Bauer[1], Sumera Ahmad[1], Alice Gallo de Moraes[1], Alexander Niven[1], Richard A. Oeckler[1], Amos Lal[1], Ognjen Gajic[1], on behalf of the CERTAIN STOP Collaborators

[1]Division of Pulmonary and Critical Care Medicine, Mayo Clinic, Rochester, Minnesota, USA;

[2]Department of Anesthesiology, Mayo Clinic, Rochester, Minnesota, USA;

[3]Department of Pulmonary and Critical Care, Virginia Mason Medical Center, Seattle, Washington, USA;

[4]Division of Pulmonary and Critical Care, Mayo Clinic, Jacksonville, Florida, USA.

*Correspondence to Rana Gur: gur.rana@mayo.edu

#Equally contributed to this work: Oguz Kilickaya and Dimitrios Kantas.

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ABSTRACT

The COVID-19 pandemic revealed significant variability in mechanical ventilation training and bedside practices, highlighting the necessity for standardized, actionable protocols. This study aimed to develop the Standard Training and Operating Procedure (STOP), an evidence-based algorithm designed for managing mechanically ventilated critically ill patients and troubleshooting patient-ventilator interactions. Utilizing the Successive Approximation Model (SAM), we reviewed current guidelines and expert recommendations, created a minimum-viable prototype during a multidisciplinary "savvy start," and refined it through seven iterative review cycles involving 33 frontline clinicians. The finalized tool underwent external evaluation via a Modified-Delphi process within the Checklist for early recognition and treatment of acute illness and injury (CERTAIN) network, engaging 50 clinicians from 19 countries across four continents, with a consensus threshold of ≥70%. STOP consists of eight sequential bedside checkpoints: abnormal vital signs/ventilator alarms, assessment of ventilation adequacy, elevated peak pressure, elevated plateau pressure, lung protection against ventilator-induced lung injury, risk of oxygen toxicity, patient-ventilator asynchrony, and readiness for spontaneous awakening and breathing trials. The Delphi agreement across these steps ranged from 82% to 96%, supporting the tool's face validity and clinical relevance. STOP offers a practical framework to minimize practice variability and enhance the safety of mechanical ventilation; however, prospective implementation studies are necessary to assess its impact on adherence and patient outcomes.

Keywords: Acute respiratory distress syndrome, autoPEEP, decision aid, mechanical ventilation, ventilator-induced lung injury, weaning.

INTRODUCTION

Inconsistent quality of critical care practice has long been identified as the main barrier to improving patient-centered outcomes [1]. This is particularly evident in the management of mechanically ventilated patients, where variability in practices underscores the need for standardized, evidence-based protocols to optimize care delivery [2]. While effective ventilator management is essential for supporting respiratory function in critically ill patients, it remains challenging for clinicians due to the variety of available ventilators, multiple ventilation modes, and complicated displays [3] and the inequal use of respiratory therapists to manage those ventilators [4]. This complexity often leads to data overload and wide practice variability, contributing to medical errors and inconsistent quality of care [5]. The COVID-19 pandemic further highlighted these challenges, as intensive care units (ICU) worldwide faced overwhelming demand, exposing disparities in mechanical ventilation training and practices across different regions [6].

Although prior research highlights the benefits of evidence-based approach to mechanical ventilation, significant gaps remain in translating them into standardized protocols, that balance modern complexity with the simplicity required for effective bedside application [7, 8]. Protocols that streamline decision-making, focusing on essential components that yield the highest impact on patient outcomes are the most likely to succeed [9].

To address these gaps, we aimed to develop a "Standard Training and Operating Procedure (STOP)" that offers a structured approach to guide the bedside mechanical ventilation management of common and/or critical conditions encountered in critically ill patients and help troubleshoot patient-ventilator interactions using current guidelines and most recent expert recommendations for best practice.

MATERIALS AND METHODS

To achieve these objectives, the STOP Project follows a multi-phase approach, with each phase involving specific ancillary projects designed to build, refine, test, and deploy the STOP algorithm in both clinical and educational settings **(Figure 1)**. In this manuscript, we have focused on the conceptual development, instructional design framework, and iterative prototyping of the STOP algorithm. The study protocol was evaluated and approved by the institutional review board (IRB).

The development of the STOP algorithm followed the principles of the Successive Approximation Model (SAM), a highly iterative approach designed for rapid prototyping and continuous refinement [10]. This model allowed us to create, test, and refine the algorithm in real time, ensuring that each version was aligned with real-world needs and evidence-based practices **(Figure 2)**.

To establish a foundation, we conducted a comprehensive review of current guidelines, best practices, and expert recommendations on the management of mechanically ventilated patients. As the next step, we initiated the "savvy start" phase of SAM. In this phase, a diverse, multidisciplinary team, including experts in critical care, respiratory therapy, pulmonary medicine, and clinical education, collaborated to develop a minimum viable prototype of the STOP algorithm. The prototype was designed to address the most common and clinically relevant scenarios in mechanical ventilation, providing bedside clinicians with a structured, easy-to-follow decision aid.

During iterative design and development phases of SAM, the prototype underwent seven rounds of iterative review by a panel of subject matter experts. This panel included critical care physicians, respiratory therapists, and nurse practitioners, each providing feedback from their unique perspectives on frontline care. In each round, the experts evaluated the prototype against criteria such as:

- Clarity: Is each step clear and easy to follow under high-pressure ICU conditions
- Feasibility: Can bedside providers realistically implement each step in diverse clinical settings?
- Clinical Relevance: Does each component align with evidence-based practices and address common ICU challenges?

In each iteration, feedback led to modifications, ensuring the algorithm was user-friendly, clinically relevant, and adaptable to various healthcare settings. For example, steps were rephrased for clarity, redundancies were eliminated, and specific metrics (like safe limits for ventilator settings) were included to provide clear guidance on decision points.

By the end of the iterative design and development phases, the STOP algorithm had evolved into a streamlined, eight-step tool tailored to address both routine and high-risk scenarios in mechanical ventilation management. Each step is designed to cover essential actions, from assessing abnormal vital signs and ventilator alarms to evaluating patient readiness for spontaneous awakening and breathing trials, with each step aimed at standardizing care and reducing variability in practice. The collaborative and iterative nature of this process ensured that the STOP algorithm was grounded in both best practices and frontline feasibility, laying a strong foundation for further refinement and testing.

Following the development of the initial STOP algorithm prototype, we conducted a Modified Delphi process to enhance its clinical relevance and usability across various ICU environments. Taking advantage of the Checklist for Early Recognition and Treatment of Acute Illness and iNjury (CERTAIN) Network [11], we engaged a global sample of multidisciplinary clinicians from 19 countries across 4 continents, who contributed their expertise in ventilator management through multiple rounds of feedback and discussion. Using the Modified-Delphi method, participants reviewed and rated each step of the algorithm to ensure practical feasibility and alignment with best practices in ventilator management. Each round included targeted questions to assess the effectiveness, clarity, and applicability of specific algorithm steps. Experts rated the feasibility and clinical relevance of each component, with a consensus defined as achieving at least 70% agreement among participants. [12, 13]

Any elements that did not initially reach consensus were intended to be revised based on participant feedback or removed from the algorithm in subsequent rounds. After the rounds we conducted a webinar with all stakeholders, where we reviewed open-ended comments and feedback gathered during the Delphi process. In addition to making final revisions, we used this forum to discuss optimal implementation strategies and future directions for the STOP algorithm, ensuring that it would be both evidence-based and adaptable to diverse clinical settings. In accordance with Delphi methodology guidelines [13, 14], formal sample-size estimation was not applied, as Delphi techniques emphasize expert consensus rather than inferential statistics.

RESULTS

Thirty-three clinicians from diverse backgrounds participated in the iterative development and internal refinement of the STOP algorithm using SAM (Table 1). Over seven SAM review cycles, the multidisciplinary expert panel reviewed successive prototypes of the algorithm with each iteration refined based on frontline feasibility, clarity, workflow integration, and alignment with evidence-based mechanical ventilation practices.

This iterative prototyping process resulted in convergence on a final 8-step procedure, each guiding the bedside provider through a structured algorithm and decision aid. (Figures S1-S4):

1. Are the vital signs abnormal and/or is the ventilator alarming?
2. Is there adequate ventilation?
3. Is the peak pressure high?
4. Is the plateau pressure high?
5. Are the lungs protected from VILI?
6. Is there a concern for oxygen toxicity?
7. Is there patient-ventilator asynchrony?
8. Is the patient ready for spontaneous awakening and breathing trial?

Throughout the SAM-based development phase, expert feedback informed targeted refinements, including reorganization of step sequencing, clarification of decision prompts, standardization of terminology and thresholds, and removal of redundancies. This process emphasized usability under real-world ICU conditions and supported the development of a coherent, clinically intuitive workflow.

Following completion of the iterative development phase, the finalized STOP algorithm underwent external expert review using a Modified-Delphi consensus process including 50 clinicians, which demonstrated high overall agreement across all eight steps (82–96%), supporting the face validity and clinical relevance of the final tool. Detailed algorithm flowcharts, operational thresholds, and supporting evidence are provided in the E-Supplement.

DISCUSSION

We present an iterative development of a structured, eight-step approach to support bedside decision-making for mechanically ventilated patients. Prioritizing relevant from irrelevant, STOP is designed to minimize errors and delays, reduce the practice variability, and standardize the care. A diverse group of clinician experts achieved a high degree of consensus across all components of the algorithm.

Previous efforts to develop decision aids and protocols for mechanical ventilation management have significantly contributed to the standardization of care and improvement of patient outcomes [2, 15]. A systematic review and meta-analysis by Parhar et al., which included more than 5,900 mechanically ventilated patients across 14 studies, demonstrated that standardized management of hypoxemic respiratory failure and acute respiratory distress syndrome (ARDS) was associated with a significant reduction in mortality and an increase in ventilator-free days compared to usual care [16]. Comprehensive ICU care frameworks, such as the PADIS (Pain, Agitation/sedation, Delirium, Immobility, Sleep disruption) guidelines [17] and the ABCDEF (Assess, prevent, and manage pain, Both spontaneous awakening trials (SAT) and spontaneous breathing trials (SBT), Choice of analgesia and sedation, Delirium: assess, prevent, and manage, Early mobility and exercise, Family engagement and empowerment) bundle [18], integrate mechanical ventilation within broader strategies to enhance overall patient outcomes. However, while these frameworks provide essential guidance for holistic ICU management, challenges remain in translating their recommendations into bedside decision-making tools that guide clinicians through the full spectrum of ventilatory management in real time. The STOP algorithm fills this gap by integrating evidence-base[17]d ventilatory strategies into a structured, stepwise approach, providing a streamlined and actionable tool to optimize mechanical ventilation and improve patient outcomes.

Protocols focusing on spontaneous awakening and breathing trials have been successful in reducing the duration of mechanical ventilation and ICU stays.[19-23] The study by Pun et al. demonstrated that complete compliance with the ABCDEF bundle was associated with a significantly lower likelihood of requiring mechanical ventilation the following day (AOR, 0.28; 95% CI, 0.22-0.36), highlighting the critical role of sedation management, delirium prevention, and early mobility in facilitating timely liberation from mechanical ventilation [24]. The STOP algorithm builds on these principles by incorporating a structured decision tree for weaning. Unlike traditional weaning protocols, STOP integrates weaning as an active step within a comprehensive algorithm, ensuring that clinicians systematically reassess readiness each time they ‘STOP’ at the bedside, allowing for continuous adaptation of ventilatory strategies to real-time patient needs.

Tools designed to guide tidal volume settings based on predicted body weight have simplified the implementation of lung-protective ventilation strategies [25, 26]. The ARDS Network guidelines recommend maintaining low tidal volumes (4-8 mL/kg of predicted body weight) while ensuring plateau pressure (Pplat) remains below 30 cm H2O to minimize VILI [27]. End-Expiratory Pressure (PEEP) optimization also plays a crucial role in lung-protective ventilation by preventing alveolar collapse and reducing cyclic opening/closing injury. Higher PEEP strategies facilitate alveolar recruitment and reduce atelectrauma, especially in patients with moderate to severe ARDS [28]. However, balancing recruitment with overdistension is critical, as excessive PEEP can lead to hemodynamic compromise and overdistension of aerated lung regions. Recent studies highlight driving pressure (ΔP), defined as plateau pressure (Pplat) minus PEEP, as a key determinant of survival in ARDS. Lower driving pressures, ideally below 15 cm H2O, are associated with improved outcomes and reduced mortality, making it an essential parameter in lung-protective ventilation [29, 30]. While these four pillars, low tidal volume, limited plateau pressure, optimized PEEP, and minimized driving pressure, are the foundation of lung protective ventilation, mechanical ventilation can also cause lung injury due to excessive inspiratory effort, leading to patient self-inflicted lung injury (P-SILI) and diaphragmatic injury (myotrauma) [31]. In patients on spontaneous ventilation modes such as Pressure Support Ventilation or Adaptive Support Ventilation, measuring the Pressure Measurement Index (PMI) and airway occlusion pressure (P0.1) is crucial. Elevated Pressure Measurement Index (PMI) or airway occlusion pressure (P0.1) values indicate increased inspiratory effort, which may worsen patient self-inflicted lung injury (P-SILI) and myotrauma [32, 33]. When excessive inspiratory effort is detected, adjusting ventilatory support or switching to controlled ventilation modes can help mitigate these risks [34]. The STOP algorithm builds upon these lung-protective strategies by providing a comprehensive framework which incorporates evaluation of underlying etiology (Step 4) and facilitates dynamic adjustments of PEEP, driving pressure, and fraction of inspired oxygen (FiO2) to optimize lung protection (Steps 5-6). Additionally, STOP emphasizes the importance of assessing patient-ventilator interaction (Step 7), addressing asynchronies that can compromise both ventilation efficacy and patient comfort. This integration ensures a holistic approach to mitigating VILI while enhancing synchronization between the patient and the ventilator, ultimately improving clinical outcomes.

Algorithms and automated systems aimed at detecting VILI or optimizing ventilation settings have also shown promise [35, 36]. A study by Herasevich et al. demonstrated that an electronic algorithm for real-time monitoring and alerting of potentially injurious ventilator settings significantly reduced exposure to harmful ventilation settings from 40.6 ± 74.6 hours to 26.9 ± 77.3 hours ($p = .004$). [37] This reduction highlights the system's effectiveness in influencing bedside practice and enhancing patient safety by minimizing VILI. While these systems are valuable for their precision and real-time capability, they often require advanced technological infrastructure and significant clinician training, which may limit their feasibility in resource-limited settings. In countries such as the USA, Canada, and China, respiratory therapists play a key role in continuously assessing ventilator settings, serving as a human alternative to electronic surveillance. However, access to trained respiratory therapists is inconsistent across healthcare systems, particularly in low-resource settings. In contrast, the STOP algorithm offers a structured, intuitive approach that enhances decision-making at the bedside, making it particularly advantageous in ICUs with limited technological infrastructure or respiratory therapist availability.

While the STOP algorithm offers a structured, standardized approach to mechanical ventilation management, several limitations must be acknowledged. First, the main focus of this study is on developing and refining the STOP algorithm within the SAM framework in instructional design. The paper does not assess its clinical effectiveness or patient outcomes. While the algorithm is based on expert insights and current evidence, further testing in real healthcare settings is needed to determine its impact on ventilator practices, patient safety, and clinical outcomes. Second, we used a Modified-Delphi consensus method to ensure the clinical relevance and face validity of the final algorithm. However, detailed psychometric analyses like inter-rater reliability measurements and round-by-round score changes were not discussed in this article. These methodological aspects will be covered in a separate manuscript focusing on the Delphi process. Therefore, the current results confirm content validity and usability but are not statistically definitive. Third, the findings may not be directly applicable to all ICU settings due to variations in resources, staffing, and care protocols. While a diverse group of clinicians was involved in the development, the implementation of feasibility may differ, especially in locations with limited respiratory therapy support or technology. Local adaptation of the algorithm and context-specific implementation strategies may be necessary. Additionally, the study did not formally evaluate human factors such as usability under high workload conditions or time constraints during development. Although STOP was designed as a user-friendly cognitive aid, empirical usability assessments are required to evaluate its performance in actual ICU workflows. Finally, STOP is intended to assist clinicians in decision-making rather than replace human involvement. Its effectiveness depends on clinician engagement, adherence, and appropriate application in the clinical context. Variations in training, experience, and workflow integration can impact how consistently the algorithm is used. To address these constraints, a prospective stepped-wedge cluster implementation and testing study (PIT-STOP) is currently underway (Figure 1). This study aims to assess real-world usability, adherence, and clinical impact in diverse ICU settings, with continuous enhancements based on feedback from frontline clinicians.

CONCLUSION

The STOP Project represents an innovative approach to improving mechanical ventilation management in critical care, bridging the complexity with a practical solution required for effective bedside applications. By providing a streamlined, evidence-based algorithm that emphasizes simplicity without sacrificing clinical relevance, STOP aims to provide a pragmatic and universal solution to standardize care, reduce variability, and ultimately enhance patient outcomes. The multi-phase development and implementation strategy ensures that STOP is adaptable to diverse healthcare environments and responsive to the needs of both experienced clinicians and trainees. Ultimately, the STOP project underscores a commitment to patient-centered, high-value care, with the goal of translating best practices into actionable bedside protocols that support ICU teams worldwide in delivering optimal respiratory support.

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TABLES AND FIGURES WITH LEGENDS

Table 1. Demographic characteristics of clinicians participating in iterative design/development phases (SAM) and external consensus phase (Modified-Delphi)

	Design and development phase (SAM) (*n* = 33)	**External consensus phase (Modified-Delphi) (*n* = 50)**
Demographic characteristics		
Gender		
Female	10 (30%)	18 (36%)
Male	23 (70%)	32(64%)
Profession		
Physician	29 (88%)	43 (86%)
Nurse Practitioner	1 (3%)	2 (4%)
Respiratory Therapist	3 (9%)	5 (10%)
Specialty distribution		
Anesthesiology	7 (24%)	12 (24%)
Internal Medicine	2 (7%)	19 (38%)
Pulmonology	16 (48%)	4 (8%)

Cardiology	0	2 (4%)
Surgery	0	3 (6%)
Pediatrics	0	2 (4%)
Emergency Medicine	2 (7%)	0
Infectious Disease	1 (3%)	0
Other	5 (17%)	8 (16%)
Years of experience		
<1	0	2 (4%)
1-5	7 (21%)	17 (34%)
6-10	6 (18%)	10 (20%)
11-15	6 (18%)	9 (18%)
Over 15	14 (43%)	12 (24%)

Abbreviation: SAM: Successive approximation model.

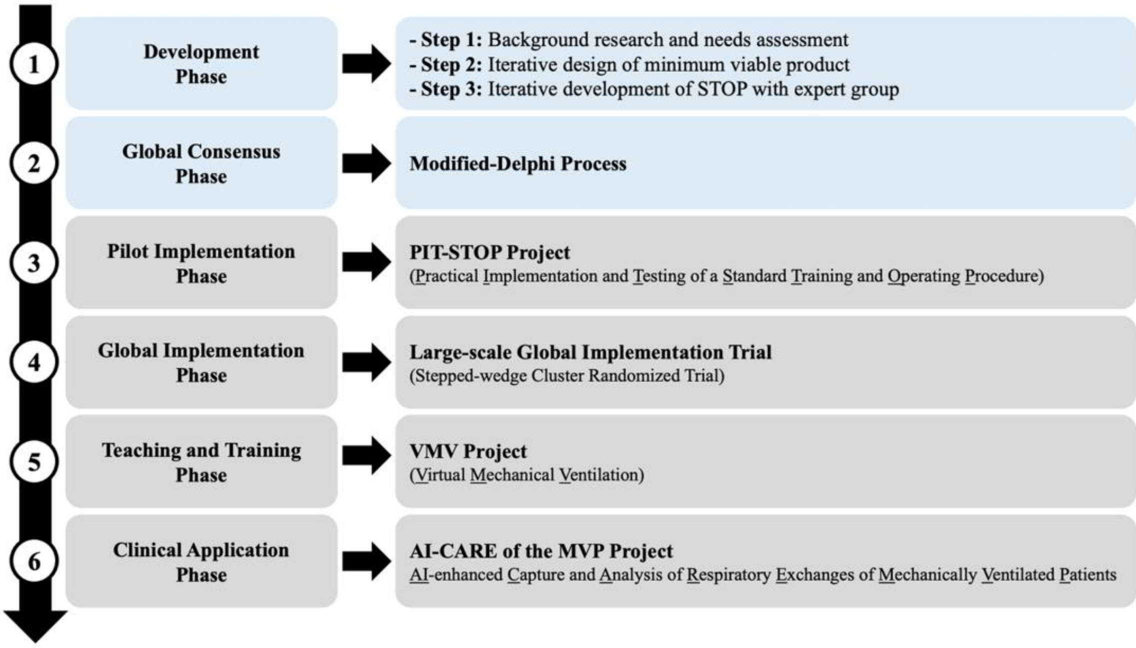

Figure 1. Overview of the STOP project's multi-phase approach. This figure presents a comprehensive summary of the project structure, illustrating a stepwise sequence of phases that outline the progression of the STOP initiative. It details the transition from initial development activities to extensive validation and subsequent implementation in practice. The figure serves as a high-level roadmap of the major stages of the project, highlighting the planned progression from foundational work to pilot testing, larger-scale implementation efforts, concurrent educational components, and downstream clinical application pathways.

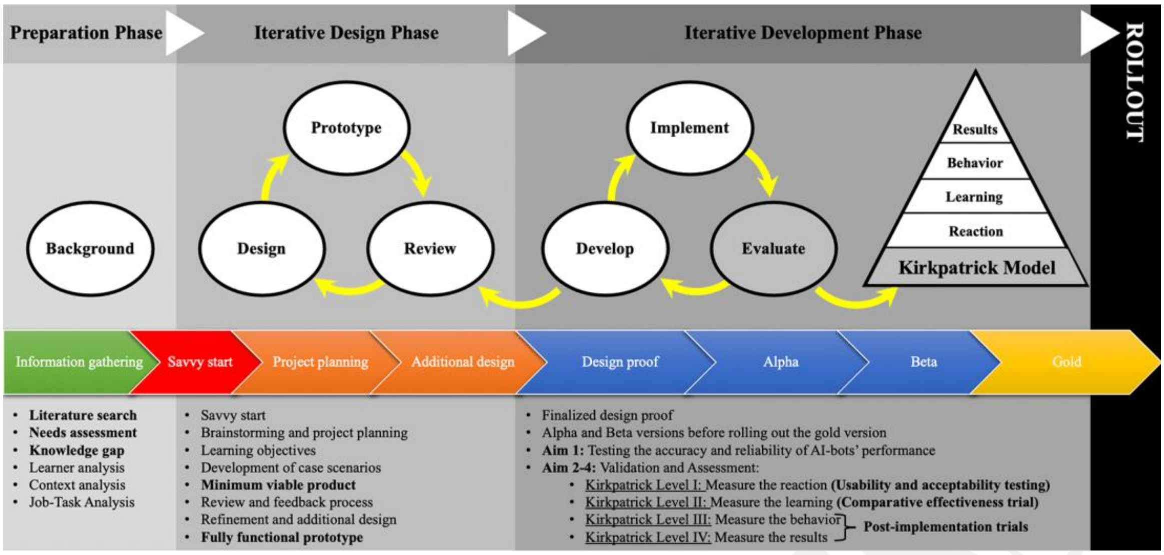

Figure 2. SAM applied to the iterative development and evaluation of STOP. This figure illustrates the iterative instructional design workflow that underpins the development of STOP, emphasizing rapid prototyping and continuous refinement through iterative cycles of design, review, and development. It depicts the progression from initial background and needs assessment and early "savvy start" activities to staged releases and rollout. Evaluation is aligned with the Kirkpatrick framework to facilitate systematic assessment throughout the implementation phases. Abbreviations: SAM: Successive Approximation Model; STOP: Standard Training and Operating Procedure.

SUPPLEMENTAL DATA

Supplemental data are available at the following link:

https://www.bjbms.org/ojs/index.php/bjbms/article/view/13288/4102