ORIGINAL RESEARCH

Use of a Portable Electronic Interface Improves Clinical Handoffs and Adherence to Lung Protective Ventilation

Neil R Euliano [1], Paul Stephan[1], Konstantinos Michalopoulos[1], Michael A Gentile [2], A Joseph Layon[3], Andrea Gabrielli[4]

[1]Convergent Engineering, Inc, Gainesville, FL, USA; [2]Department of Anesthesiology, Duke University, Durham, NC, USA; [3]Department of Anesthesiology, College of Medicine, University of Central Florida, Orlando, FL, USA; [4]Miller School of Medicine, University of Miami, Miami, FL, USA

Correspondence: Neil R Euliano, Convergent Engineering, Inc, 100 SW 75th Street, STE 106, Gainesville, FL, 32607, USA, Tel +1 352 378 4899 x 107, Fax +1 352 378 9202, Email neil@conveng.com

Background: Mechanical ventilation (MV) is used to support patients with respiratory impairment. Evidence supports the use of lung-protective ventilation (LPV) during MV to improve outcomes. However, studies have demonstrated poor adherence to LPV guidelines. We hypothesized that an electronic platform adapted to a hand-held tablet receiving real-time ventilatory parameters could increase clinician awareness of key LPV parameters. Furthermore, we speculated that an electronic shift-change tool could improve the quality of clinician handoffs.

Methods: Using a specially designed Wi-Fi dongle to transmit data from three ventilators and a respiratory monitor, we implemented a system that displays data from all ventilators under the care of a Respiratory Care Practitioner (RCP) on an electronic tablet. In addition, the tablet created a handoff checklist to improve shift-change communication. In a simulated ICU environment, we monitored the performance of eight RCPs at baseline and while using the system.

Results: Using the system, the time above guideline Pplat decreased by 74% from control, and the time outside the VT range decreased by 60% from control, p = 0.007 and 0.015, respectively. The handoff scores improved quality significantly from 2.8 to 1.6 on a scale of 1 to 5 (1 being best), p = 0.03.

Conclusion: In a simulated environment, an electronic RT tool can significantly improve shift-change communication and increase the RCP's level of LPV adherence.

Keywords: respiration, lung protective ventilation, handoff, respiratory therapy, clinical decision support software, health information technology

Introduction

Mechanical ventilation (MV) is an integral part of care for critically ill patients. Lung-protective mechanical ventilation (LPV) is a strategy aiming to reduce the incidence of ventilator-induced lung injury.[1–3] Perioperative use of LPV has also shown benefits in patients without preexisting lung impairment, suggesting a role in reducing pulmonary complications and length of stay.[4,5] LPV focuses on reducing the stress of lung opening, or barotrauma, and lung parenchymal strain, or volutrauma.[1,6] The evidence that LPV is potentially life-saving was reported over 20 years ago by the NHLBI ARDS Net Group as they applied tidal volume (V_t) between 4 and 8 mL/kg predicted body weight (PBW) and Plateau pressure (Pplat) <30 cmH$_2$O for patients receiving MV.[1,7] While these findings have achieved the status of Best Practices, their implementation into routine clinical care has proven to be a complex task. Indeed, there are data indicating that clinicians still do not effectively implement these LPV strategies.[8,9]

Several studies have identified barriers to guideline adherence, including lack of awareness, lack of familiarity, lack of agreement, lack of outcome expectancy, and inertia of previous practice.[10] More specifically, reported reasons for non-compliance with LPV standards include: (1) wrong calculation of predicted body weight (PBW, also termed Ideal Body

Weight [IBW]); (2) underdiagnosed ARDS despite international standards of definition; (3) perceived patient discomfort from low V_t ventilation, and (4) knowledge gap in recognizing and treating patient-ventilator asynchrony.[11–13] Many of these barriers may be overcome by enhancing communication between Respiratory Care Practitioners (RCPs) and other bedside personnel, increasing awareness of patient–ventilator interaction and consolidating key patient information in a user-friendly format, both in real time and during clinical handoffs. Several studies have demonstrated that simple communication tools can be used to improve compliance with LPV ventilation.[14,15]

While optimization of patient–ventilator interaction is multidisciplinary, RCPs have a central role in managing ventilator settings. Still, they face many challenges in implementing evidence-based medicine at the bedside in critically ill patients: maintaining compliance with best ventilator practices, patient situational awareness while facing high patient workload, and efficient communication during clinical handoffs. It has been demonstrated that the implementation of a standard handoff bundle could reduce preventable adverse events by 30%, without increasing transition of care time.[16] Several key actions suggested by The Joint Commission to improve the quality of transition of care include standardized content between sender and receiver including standardizing tools and methods (eg checklists), face-to-face handoff in a quiet environment, use of electronic health record capabilities and other technologies (apps and patient portals) to enhance hand-offs, and process improvement through monitoring success of interventions.[17]. Electronic adjuncts are an alternative strategy to increase compliance with LPV by providing continuous physiological feedback, cognitive prompts, and behavioral nudges.[18]

We created such a system to increase awareness of LPV parameters and improve clinical handoffs conducted at shift change and then assessed the efficacy of this electronic platform. We hypothesized that an electronic platform adapted to a hand-held tablet receiving real-time ventilatory parameters such as V_t, frequency of mechanical breaths (f), flow/volume graphs, and alarms, and containing an efficient handoff checklist could assist RCPs in maintaining established LPV parameters (Pplat <30 cmH$_2$O and V_t 4 to 8 mL/kg PBW) and improve hand-offs.

Materials and Methods

To collect and distribute data wirelessly, we designed Wi-Fi dongles for three mechanical ventilators (Puritan Bennett 840, Medtronic Inc., Boulder, CO; Drager V500, Drager Inc, Telford, PA; Hamilton G5, Hamilton Medical Inc, Reno, NV) plus a respiratory graphics monitor (NM3, Philips Healthcare Inc, Carlsbad, CA) (Figure 1). The dongles were programmed to read data from the serial ports of the four devices and transmit them wirelessly to a custom-designed server. The server collected the data from each ventilator, performed calculations, and transmitted the data to a tablet computer-based mobile application carried by each RCP. The mobile application contained (a) a dashboard screen showing all patient respiratory parameters and alarms, (b) a detailed screen for each patient, and (c) a sequence of clinical handoff pages (Figure 2). The mobile application was designed to provide RCPs with continuous, real-time V_t, f, pressure/volume waveforms, plateau pressures, and indications of alarms from the ventilators, all displayed on an 8-inch tablet (Samsung, Galaxy Tab A, San Jose, CA) during the clinical simulation. The tablet user interface was designed after an online survey of over 175 practicing RCPs determined minimum data practitioners wanted the ability to access, and the optimal information required for clinical handoff. The mobile application provided efficient data entry to record medication administration and clinical information (blood gases, chest radiographs, breath sounds, suctioning, etc.) via check boxes, radio buttons, and pop-up selections, which could be accomplished within 15 seconds. Parameter changes and patient data were automatically downloaded from the patient's ventilator. All information was available at all times for all patients simultaneously and used to populate the clinical handoff template defined by the team.

To develop the clinical handoff template, ten different RCPs and RT Managers collaborated to reach a consensus on the minimum information that should be included (Figure 3). This template was then used to create an electronic shift report guide within the tablet (RT Assistant, Convergent Engineering, Gainesville, FL).

Next, a mock intensive care unit (ICU) was created (Santa Fe College, Gainesville, FL). This ICU was populated by four simulated patients requiring MV in a control group, and 4 similar patients in the study group. After obtaining informed consent, eight RCPs participated in this simulation study, performing care for both the control and experimental group. The essential qualities of the scenarios (e.g., changing compliance, airway resistance, f, V_t) were maintained between the two groups but were disguised with different demographics, admission diagnosis, and clinical interventions. Each set of simulations was designed to be an accelerated clinical shift, including three rounds of bedside patient
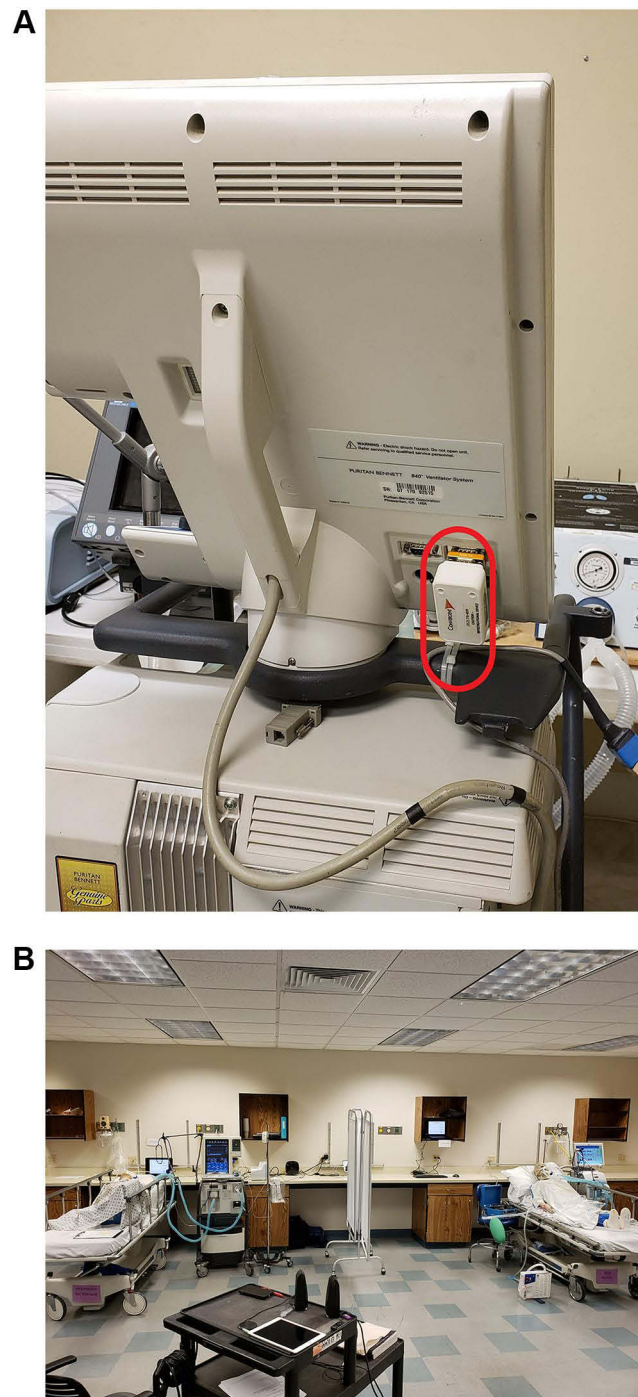
Figure 1 Wi-Fi dongle connected to the serial port of a Puritan Bennett 840 Ventilator (**A**). One room of the simulated ICU (**B**).

assessments, aerosolized bronchodilator administration, endotracheal suctioning, patient transport, and other activities that could be completed within four hours.

For the control group, each of eight RCPs, from three different hospitals, were provided with a scripted clinical handoff report from one of the primary investigators and asked to care for the simulated patients as they would in their hospital practice. The investigator reviewed the significance of LPV guidelines with the RCP before the study. The Wi-Fi dongles attached to the ventilators and respiratory monitors collected data continuously throughout the control study, but the RCPs were not aware of these devices. After completion of the simulated shift, the RCPs were asked to provide a shift report to two
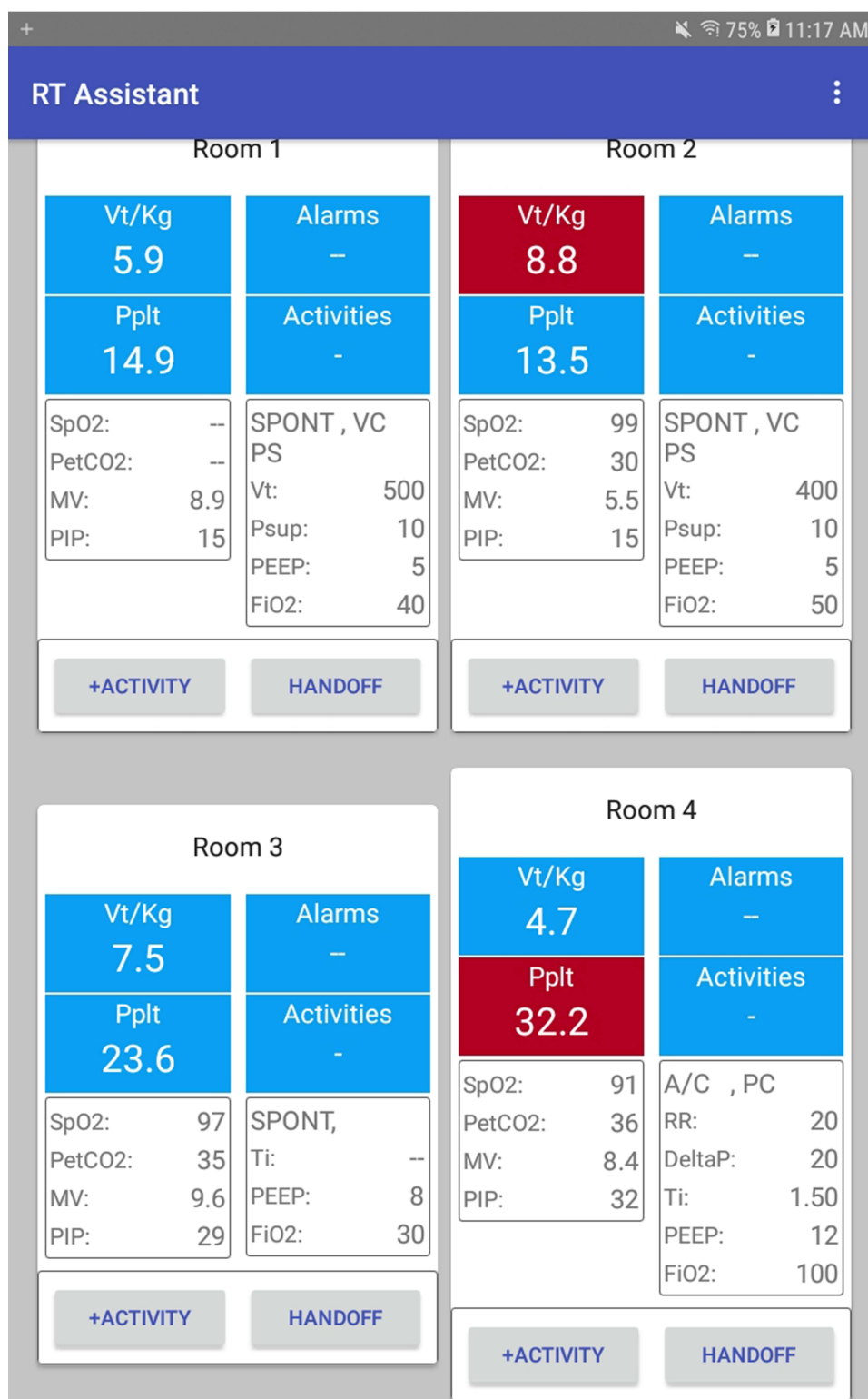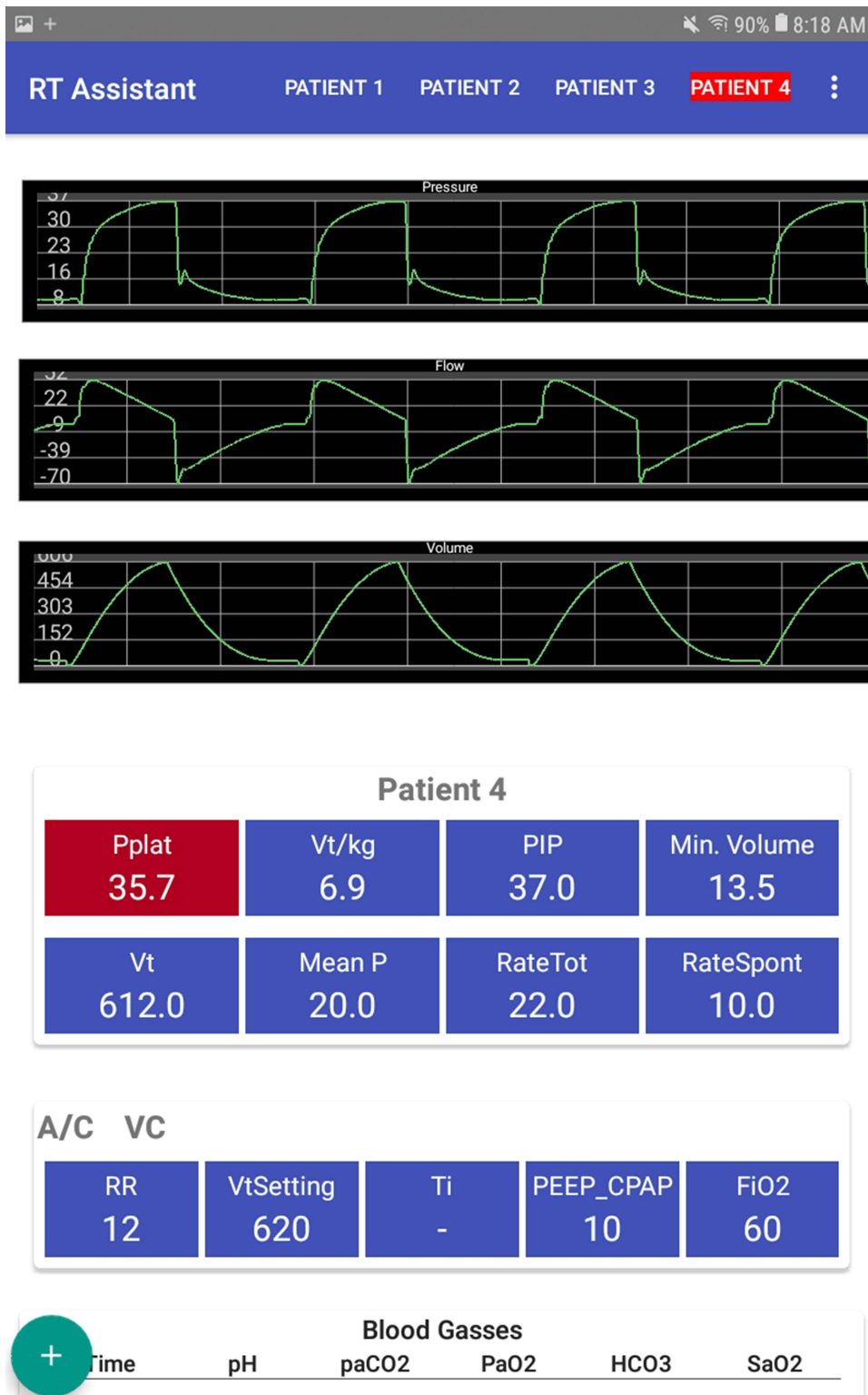
A

Figure 2 Continued.

Figure 2 Continued.

C

Figure 2 Mobile application key features (**A**), (**B**), and (**C**). (**A** and **B**) are real time displays. (**A**) A dashboard screen that showed the patient's key respiratory parameters and alarms. (**B**) A detailed waveform profile for each patient. (**C**) A sequence of clinical handoff pages.

SHIFT REPORT

Date **2019-06-29** Receiver shift: ● Night ○ Day ○ Afternoon

Patient name **TJT**   Room/Bed Number **W4218**

Age **72** Gender **Male**   Height **1.8m** PBW **80**

I	**Illness Severity** ● Stable ○ Unstable NOTES: _____

P

Patient Summary

Primary diagnosis: **Pmeumonia, Significant COPD with CO2**

ETT Size **8** Taped at: **lip, 36** Cuff Press **24** Vent Days **4**   Diff Airway? **NO**

Chest Tubes: Left **1** Right **0** Suctioning **Yes**

Code Status: CPR: **Yes**, Intubate: **Yes**

Ventilator / Respiratory status:

    Vent Settings: mode **PSV** PSV: **10**, PEEP: **10**, FIO2: **0.40**

    Patient status: Pplt **13** Vt/PBW **6.7** Driving Pressure **23**   FIO2/SpO2 **94%**

    Blood Gas History:

Time	pH	PCO2	PaO2	HCO3	O2Sat
06-28 05:30	7.36	58	64	32	0.94

Sedation: **Yes- RASS 1**   Sedation Infusions: **Fentanyl**   CV Infusions: **None**

SBT (SABT) History:

Type	Scheduled	Started	Duration	Settings	Success?	Failure Cause /not started
SBT	6/29 06:00	06/29 07:30	20 min	10/5 0.3	No	**Increased SOB, increased F, SpO2 85%**

CXR: time **2019-06-26 05:15** status **Pneumonia, depressed diaphragms**

NOTES: _____

A

Action List

Next Due	Action	Timing	Response/Notes
12:30	SBT	Q24	
14:30	ABG	Q12	
15:30	Nebulizer Tx with Duoneb	Q6	
10:15	Transport to XRay		

S

Situational Awareness (Concerns, problems, issues, contingencies)

SBT stopped due to distress, suggest IRT to strengthen muscles, continue daily SBT and pulmonary therapies. Secretions problematic. Spanish speaking.

S

Synthesis (Questions and clarifications)

Receiver summary and Q&A

Notes: _____

Figure 3 A consensus shift report template containing minimum information required.

senior clinicians who graded the shift report using checklists and a 9-question 5-point Likert scale questionnaire. The checklists were created by compiling information from the scenarios and the minimum information shift report described above to provide a simple method for evaluating the amount of critical information transmitted during the shift report. The RCP also filled out a 5-point Likert scale questionnaire to self-evaluate their performance.

For the experimental group, the same 8 RCPs who participated in the control group were presented with scenarios similar to the previous exercise. The RCPs were first trained on the use of the RT Assistant mobile application and again reminded of the LPV practice guidelines. The training required approximately 15–20 minutes to complete. All RCPs demonstrated proficiency in use of the software. After their simulated shift, the study group used the RT Assistant to provide a structured shift-report to the same senior clinicians. As previously noted, data were collected from the ventilators and respiratory monitor and surveys were filled out by the receiving clinicians and RCP. Additional questions were asked of the RCP to evaluate the effectiveness and ease-of-use of the RT Assistant interface.

All research-related activities were approved by the Western Institutional Review Board (WIRB). Written and informed consent was obtained from all active participants. The anonymous online survey received a waiver of informed consent.

Description of Scenarios

The simulated ICU environment consisted of eight simulated patients with severe respiratory failure of different etiologies who were intubated and mechanically ventilated. Demographics, initial conditions, and required treatments and interventions were also different. Table 1 shows the scenarios studied for the control group. The experimental group

Table 1 Virtual Scenarios Presented to the Control Group

Control Group		Scenario 1	Scenario 2	Scenario 3	Scenario 4
Demographics	Age	33	58	58	42
	PBW	75	57	57	89
	Sex	M	F	F	M
	Dx	Pt. received from the OR, S/P exploratory lap from knife wound.	Pt admitted due to increase SOB. Dx pulm edema. Hx of CAD.	Pt admitted for increase SOB, Dx CA. In hospital for 2 weeks, intubated 7 days prior.	Admitted to ICU with a diagnosis of worsening Sepsis. Decreasing SpO_2, increasing Pplat, decreasing Cst.
Shift change VENT SETTINGS	Mode	AC/VC	VC+	PC/AC	VC/AC
	RR	12	8	14	12
	Vt	530	400	400	620
	PS		10		
	FiO$_2$	0.60	0.50	0.40	0.60
	PEEP	12	10	10	10
	Ti		0.9	1.2	
	Delta P			17	
	Changing patient conditions	RCP called to evaluate following decreased SpO_2. Clinical deterioration, SpO_2 below 90%, worsening compliance, increasing Pplat beyond LPV guidelines.	Pt diuresed aggressively overnight. Spont V_ts improve, Cst increases, Pplat decreases. V_t increase above LPV guidelines. SBT attempted but failed.	Chest tube insertion, SpO_2 above 90%, improving compliance, increasing tidal volume beyond LPV guidelines. Delta P weaned.	SpO_2 decreases overnight. Pplat rising, Cst decreasing. FIO_2 needs increasing and PEEP increasing to maintain SpO_2 above 90%. Pplat over LPV guidelines.

(Table 2) consisted of similar patients disguised with different demographics to minimize the RCP learning effect but still allow comparison.

Results
LPV Improvement

Although all RCPs were reminded of the LPV guidelines (Pplat below 30 cmH$_2$O and V$_t$ between 4 and 8 mL/kg/PBW) before the beginning of each phase of the study, the Pplat was above the LPV guideline $26.6 \pm 7.1\%$ of the time and the V$_t$ was outside the range $19.5 \pm 5.3\%$ of the time during the control group testing. With the use of the RT Assistant (experimental group), by providing the RCP more LPV awareness, even when not in the patient's room, the time above the Pplat dropped by 74% (to $7 \pm 4.1\%$) and the time outside the V$_t$ range dropped by 60% (to $7.8 \pm 3.3\%$). The Wilcoxon Signed Rank Test indicated both values were significant at p-values of 0.007 and 0.015, respectively.

Table 2 Virtual Scenarios Presented to the Experimental Group. For Ease of Comparison, Modifications of the Demographic Data and Evolution of the Disease from the Control Group Was Carried Out for the Experimental Group

Experimental Group		Scenario 1	Scenario 2	Scenario 3	Scenario 4
Demographics	Age	58	67	31	65
	PBW	78	57	64	75
	Sex	M	F	F	M
	Dx	Cardiac arrest in field. CPR via EMT's, Pt transported to cath then to OR for CABG.	Patient admitted 2 weeks prior with Dx SAH. S/P clipping, trached 2 days prior to assist with weaning efforts.	Patient admitted 3 days prior for MVC. Multiple rib fx's, worsening infiltrates via chest x-ray.	Patient admitted to ICU 12 hours ago S/P GI bleed. Possible aspiration during intubation.
Shift change VENT SETTINGS	Mode	AC/VC	SIMV/PS	AC/PC	AC/VC+
	RR	10	8	12	14
	Vt	540	400	450	530
	PS		10	12	
	FiO$_2$	0.40	0.40	0.60	0.50
	PEEP	8	5	10	5
	Ti	1	1.1	1.2	1
	Delta P	20		22	
		RCP called to evaluate high pressure alarm. LPV guidelines out of bounds as Pplat and PIP increasing. RCP administers a Beta agonist.	Strong overnight diuresis, frequent suctioning, decreasing Raw. Continue to wean to SBT. Spontaneous V$_t$ increases as Raw decreases. Maintain LPV guidelines.	Worsening BS, decreased Cst, decreased SpO$_2$, increased Pplat, breach of LPV guidelines. Patient sedated, bronch performed, Pplat decreased, Raw improved.	Patient develops bronchospasm, elevated Pplat and PIP, decreased SpO$_2$. RCP to assess breach of LPV guidelines. Beta agonist nebulized patient Raw decreases.

Table 3 Subset of the Results of the Satisfaction Survey During the Experimental Group. The Full Results of the Survey are Provided in the Online Supplement

Question	Average Score
RT Assistant helps improve patient care	1.0
RT Assistant improve LPV care	1.0
RT Assistant improves patient safety	1.1
RT Assistant dashboard screen is useful	1.0

Clinical Handoff Improvement

The percentage of data transferred during the shift change – as quantified by the checklists – increased significantly during the experimental group from 45% (control) to 63% (experimental), with a p-value of essentially zero at all possible alpha levels (two proportion z-test).

The average shift report score – average of 9-question Likert questionnaire evaluated by staff clinicians – improved significantly with the use of the RT Assistant from 2.8 to 1.6 on a scale of 1 to 5 with 1 being best. The Wilcoxon Signed Rank Test resulted in a p-value of 0.03 with an alpha level of 0.05.

The mean time required to complete the handoff increased from 7.8 ± 2.0 minutes during the control study to 12.8 ± 32.9 minutes with the RT Assistant. This increase was expected due to the increased quantity and quality of the information transmitted and, possibly, due to initial unfamiliarity with the tool. Anecdotally, we noticed that without the RT Assistant, most RCPs spent at least 5 minutes collecting and organizing their data for the shift-report. No time was spent preparing for the shift report with the RT Assistant.

RCP Satisfaction Scores

The RCP's evaluation of their experience with the tool during the experimental group was positive (Table 3). On a scale of 1 to 5 using a 10-item questionnaire (1 indicating definitely satisfied), 8 of the 9 questions resulted in a score of 1.4 or less.

Discussion

The main finding of this study was that an electronic platform adapted to a hand-held tablet receiving real-time ventilatory parameters can increase RCP's awareness of two key LPV parameters: Pplat <30 cmH$_2$O and V$_t$ between 4 and 8 mL/kg PBW. Furthermore, an electronic checklist can improve the quality of RCP handoffs. We chose to apply the intervention to a group of experienced RCPs who functioned as their own control, changing the scenarios between the control and experimental phases, including change of demographics, evolution of the scenarios, and recommended interventions. Despite the group's seniority, LPV in the control group was out of recommended range for 19.5 to 26.6% of the time. It is quite conceivable that this number would be more significant for less experienced RCPs as, almost 20 years from the initial recommendation to set mechanical ventilation in ARDS, LPV remains underutilized. There is a clear need to explore innovative alternatives to improve compliance to evidence-based medicine in this matter, and we submit that well-designed electronic tools might be the answer. LPV is an obvious choice for improving compliance, but many other "nudges" or context-sensitive reminders could be implemented easily (spontaneous breathing testing, oxygenation, driving pressure, clinical protocol adherence, and extubation readiness).

In the experimental group, the time above the Pplat limit dropped by 74% (to $7 \pm 4.1\%$), and the time outside the recommended V$_t$ range decreased by 60% (to $7.8 \pm 3.3\%$) when the electronic system was used. Continuous, instead of intermittent, awareness resulted in more frequent ventilator adjustments in the right direction to more closely follow the LPV guidelines. Based on the remarkable increase in the use of LPV in the experimental group, it is very likely that this approach would also benefit other monitored parameters such as driving pressure.

Fragmentation of care is an unfortunate, but real, phenomenon of longitudinal hospital care. While mnemonics may help, they often miss details of patient–ventilator interaction without a systematic checklist. The tested software was designed to not only improve compliance with the LPV guidelines but also enhance communication between RCPs.

Using the automated checklist, we noted a significant increase (absolute change of 18%) of handoff data transmitted between the control and the experimental group. In our study, the mean time to deliver the shift report increased from 7.8 ± 2 minutes during the control study to 12.8 ± 2.9 minutes when the RT Assistant was used. We expected a more detailed report to take more time than a memory checklist, as there is often a trade-off between quality and time. However, the increased time needed to transmit the electronic handoff was offset by a faster preparation of the shift report, which was automatically prepopulated with information obtained by the system.

We hypothesized that the electronic system increased the RCPs' level of LPV awareness by continuous, real-time feedback. This electronic application integrated well with the RCP workload. This highly demanding workflow often creates difficulties obtaining appropriate situational awareness and causes personnel dissatisfaction. In a 2016 survey of RCPs, the most significant source of dissatisfaction amongst RCPs was that they were overburdened due to staffing shortages, high patient-to-clinician ratio and the increasing workload without additional staffing resources.[19] A potential advantage for the handheld system is improved situational awareness that is achieved from the mobile data delivery from all patients to the clinician. Situational awareness and response times can suffer when RCPs are overburdened.

In a survey of 130 managers, 30% indicated they do not have adequate staff, and 21% noted that they have significant and chronic understaffing; 30% of these directors felt that patient safety issues resulted from the understaffing.[20] Staffing problems will likely continue since the Bureau of Labor Statistics indicates that the need for new RCPs will grow 23% over the next ten years and 30,000 more RCPs will be needed.[21] The COVID-19 pandemic stretched clinician staffing further and highlighted the need for improved efficiency tools.

We consider the simplicity and cost-effectiveness of this stand-alone hardware-software as an advantage. The system consists of electronic dongles on the medical devices, a dedicated server controlled by the hospital, and a mobile application developed in Java and running on Android. These are open platforms, easily adaptable to meet local needs and logistics. We believe this system is a logical first step towards future platforms that can provide additional decision support, including the Artificial Intelligence and Internet of Things (AIOT) framework.

Limitation

Our study represents an in vitro, preliminary observation and presents several limitations. The application of mechanical ventilation is complex with many variables. We focused our monitoring on 2 LPV parameters, V_t and Pplat. Further investigation is required for other settings and parameters such as PEEP, FiO_2, respiratory rate, and driving pressures used in mechanical ventilation.

Secondly, we appreciate implementation of electronic prompters can be complex and not well received by healthcare professionals. Loss of autonomy by increasingly relying on remote monitoring and alarms, in particular, is often perceived as intrusive. Behavioral economic strategies are introduced in the handheld display, with menu choices and color code to prioritize LPV tasks.[18,22] These alarms may be preset or allowed to be determined by the individual practitioner.

Conclusion

We have demonstrated that using simple electronic monitoring system, LPV awareness and patient clinical information during electronic handoff significantly improves. This introduces a tool that may be helpful for clinicians in providing safe care for patients receiving mechanical ventilation. Their actual feasibility and effectiveness will need to be evaluated in vivo – that is in a multicentered, randomized setting – before instituting a systemic implementation of process learning and measuring its effect on the outcome. We are currently in the process of verifying these results in a patient study at two academic medical centers in Florida.

Code Availability

Code is proprietary.

Data Sharing Statement

The datasets used and/or analyzed during the current study are available from the corresponding author upon request.

Ethics

All research methods were carried out in accordance with relevant guidelines and regulations. No animals were used in this research. Oversight of this study was provided by the Western Institutional Review Board (WIRB).

Consent to Participate

Western Institutional Review Board (WIRB) approved and informed consent was obtained from all individual participants included in the study.

Disclosure

Neil R. Euliano is the president and owner of Convergent Engineering, Inc. Paul Stephan and Konstantinos Michalopoulos are employees at Convergent Engineering, Inc. The authors report no other conflicts of interest in this work.

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