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A multicenter population-based effectiveness study of teleintensive care unit-directed ventilator rounds demonstrating improved adherence to a protective lung strategy, decreased ventilator duration, and decreased intensive care unit mortality[☆]



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ABSTRACT

Purpose of the study: The purpose of the study is to determine if teleintensive care unit (ICU)-directed daily ventilator rounds improved adherence to lung protective ventilation (LPV), reduced ventilator duration ratio (VDR), and ICU mortality ratios.

Method used: A retrospective observational longitudinal quarterly analysis of adherence to low tidal volume LPV (<7.5 mL/kg predicted body weight; PaO₂/fraction of inspired oxygen <300), ventilator duration, and ICU mortality ratios (Acute Physiology and Chronic Health Evaluation IV-adjusted). The teleICU practice used Philips (Andover, MA) VISICU eCareManager™ (Andover, MA) platform, providing ICU care and process improvement.

Results: Before ventilator rounds implementation, there was wide variation in hospital adherence to low tidal volume (29.5 ± 18.2; range 10%–69%). Longitudinal improvement was seen across hospitals in the 3 Qs after implementation, reaching statistical significance by Q3 postimplementation (44.9 ± 15.7; *P* < .002 by 2-tailed Fisher exact test), maintained at 2 subsequent Qs (48% and 52%; *P* < .001). Ventilator duration ratio also showed preimplementation variability (1.08 ± .34; range 0.71–1.90). After implementation, absolute and significant mean VDR reduction was observed (0.92 ± .28; −15.8%, *P* < .05). Intensive care unit mortality ratio demonstrated longitudinal improvement, reaching significance after the Q3 postimplementation (0.94 vs 0.67; *P* < .04), and this was sustained in the most recent Q analyzed (0.65; *P* < .03).

Conclusions: Implementation of teleICU-directed ventilator rounds was associated with improved and durable adherence to LPV and significant reductions in both VDR and ICU mortality.

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1. Introduction

Despite the landmark acute respiratory distress syndrome (ARDS) net study in 2000 demonstrating reduced hospital mortality and decreased ventilator days associated with the adoption of low tidal volume (V_t)-based lung protective ventilation (LPV) for patients with ARDS, real-world adherence to this strategy has remained limited. In fact, one recent survey in a major academic medical center revealed only 31.2% of ventilator settings met low V_t benchmark for LPV in eligible patients [1–3]. Moreover, accumulating evidence suggests additional benefit to early and protocolized adoption of LPV in patients with milder forms of acute lung injury (ALI) as well [4].

Factual deficit alone does not appear to be a factor in the failure to implement or maintain LPV. Medical residents, hospitalists, and intensivists alike have a high level of awareness of the findings of the ARDSnet study and when surveyed are consistently able to site the appropriate standard [5,6]. Despite the basic knowledge that low V_t improve outcome, many other limitations to adherence have been cited. Prominently cited limitations are diagnostic uncertainty for ALI/ARDS, a poor estimate or calculation of the PaO₂/fraction of inspired oxygen (FiO₂) (P/F) ratio, and predicted body weight (PBW)-based V_t. In addition, there appear to be organizational and management challenges to its implementation including the absence of an effective protocol to target and monitor adherence and a lack of time or structure to bring together dedicated staff. Finally, there is practitioner bias that excludes eligible patients borne out of a perception of physiologic worsening, symptom burden, and increased sedative need associated with LPV settings despite evidence to the contrary [7–9].

Teleintensive care unit (ICU) platforms permit off-site electronic monitoring, data acquisition, and intervention services with

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videoconference capability [10]. Models of teleICU vary by environment, structure, and protocol, with reported outcome measures that differ. A common focus, enhanced by automated teleICU systems, is to monitor and enhance best practice adherence [11–13]. In this regard, teleICU platforms may augment bedside adherence to ventilator benchmarks through automated calculation and display of P/F ratios, PBW-based Vts as well as by virtue of additional monitoring staff with a process improvement focus.

This study sought to determine if teleICU-directed daily ventilator rounds led to improved adherence to LPV and to examine whether this process was associated with improved outcome measures including reduced ventilator duration and ICU mortality.

2. Methods

We conducted a retrospective, population-based, cross-sectional, and longitudinal analysis before and after implementation of teleICU-directed daily bedside ventilator rounds. This retrospective analysis examined the effect of exposure to teleICU-directed ventilator rounds on one process and 2 outcome indicators. The process examined was adherence to low Vt benchmark, and the outcome measures were ventilator duration ratio (VDR) and ICU mortality ratio.

2.1. Monitoring center setting/teleICU systems

This study was conducted by an independent teleICU practice using Philips (Andover, MA) VISICU-licensed eCareManager™ (Philips Healthcare, Andover, MA) platform. This practice provides continuous patient surveillance, with all patients evaluated upon admission by board-certified intensivists and followed daily by teleICU critical care registered nurse (CCRN) with intensivist involvement for clinical matters of importance. Activities include acute management as well as structured process and workflow to ensure best practice compliance, with particular emphasis on deep vein thrombosis prophylaxis, glycemic control, stress ulcer prophylaxis, and low Vt ventilation.

The teleICU practitioners worked in a team assigned to a cluster of hospitals, with each practitioner stationed at a multiscreen monitor array. Clinical monitoring tools that are accessible through these workstations include real-time interfaces with each hospital information system, clinical practitioner order entry system (CPOE), radiology imaging systems, bedside monitors as well as bedside teleconference capability.

Teleconference equipment has high fidelity suitable to read ventilator settings and graphic displays. Clarity of patient examination by this method is sufficient to remotely assess details required for assessment of liberation readiness. These include assessment of patient level of consciousness, comfort, cooperation, signs of increased work of breathing, ventilator dyssynchrony, and with assistance of bedside personnel, to assess airflow limitation and secretions.

Each practitioner workstation contains a central screen linked to eCareManager. This data management platform is used to pull data from each hospital's electronic medical record (EMR) in real time into a uniformly formatted single-page, graphically enhanced spreadsheet, similar to a comprehensive flow sheet. Through eCareManager™, the teleICU practitioner can readily access individual patient data when called to intervene or conduct rounds. Imbedded capabilities include alert icons that flag all patients receiving mechanical ventilation, calculation of a P/F ratio, Vt in milliliters per kilograms PBW, documentation of pulmonary mechanics, display of ventilator settings, and arterial blood gas analysis (ABG) results. Orders can be entered via eCareManager™, which are transmitted securely to each ICU nursing station. Alternatively, the hospital CPOE can be accessed remotely by the teleICU intensivist in similar fashion to bedside practitioners who access CPOE and EMR through desktop stations within the ICU.

2.2. Patient care setting

Eleven hospitals were included that subscribed to teleICU services during both preventilator and postventilator rounds implementation. Participating institutions were moderate-sized community hospital ICUs from a wide geographic distribution.

Participating centers used diverse hospital information system/CPOE, protocols as well as differing practice and staffing models. The ICU size ranged from 8 to 28 bed units. None of the centers used a fully closed model ICU, with the most frequent model being bedside intensivist coverage limited to daytime hours and ventilator management responsibilities shared with consulting pulmonary, hospitalist services, and intensivists. Rotating family practice house-staff was present in one of the ICUs.

2.3. Development of the template ventilator rounds checklist instrument and process

The established target for the clinical project was to facilitate a daily, organized appraisal of proper adherence to low Vt ventilation in intubated patients and when appropriate, extubation. The central organizing instrument of this process was a checklist to help ensure that teleICU practitioners evaluated ABGs, secretions, sedation levels, PBW-based Vts, and P/F ratios.

Initially, these tasks and data entry were recorded on a paper checklist template. In the second year of this process, there was a transition to an electronic format for this checklist (Fig. 1). This electronic format was designed by a teleICU Information Technology personnel (author JT) with automated dropdown list functionality to facilitate its completion and for the transmission of information through intranet access for all participants. This format also allowed for automated database entry and retrieval.

2.4. TeleICU ventilator rounds

Ventilator rounds were phased into practice one hospital at a time over a 2-year implementation period schematically depicted in Fig. 2. In preparation for implementation in each hospital, at least one meeting between teleICU medical directors and the local physician, nursing and respiratory therapy was devoted to ventilator rounds orientation. These meetings were held to introduce the topic of ventilator rounds and describe the scope and intended purpose. These introductory meetings also provided a forum for discussion and consensus on joint goals for process improvement and familiarity and endorsement of benchmark standards as well as logistic details such as timing of daily rounds and who would be participating. Before implementation, the teleICU intensivist medical group was provided guidelines for conducting ventilator rounds that included the goals and agreed upon benchmark guidelines for LPV and orientation to the internal checklist form.

Once initiated in a given hospital, multidisciplinary ventilator rounds occurred at set times, with daily participation of teleICU physicians using audiovisual link and phone calls to bedside respiratory therapist and nursing.

Each member of the multidisciplinary team entered their observations in the ventilator rounds template. For each patient, sedation level and interruption schedule were entered by teleICU nursing personnel. Bedside nursing was contacted by teleICU nursing personnel to obtain information regarding secretions and airflow limitation. Midlevel personnel reviewed the vent rounds template that contain information gathered from the electronic record including auto-populated Vt/kg PBW, ventilator settings, ABG, chest X-ray, minute volume and made an overall assessment of potential liberation readiness. When documented in the EMR, bedside respiratory therapy notes were reviewed.

Informed by these prepopulated elements, the teleICU intensivist then made teleconference contact with respiratory therapy and bedside

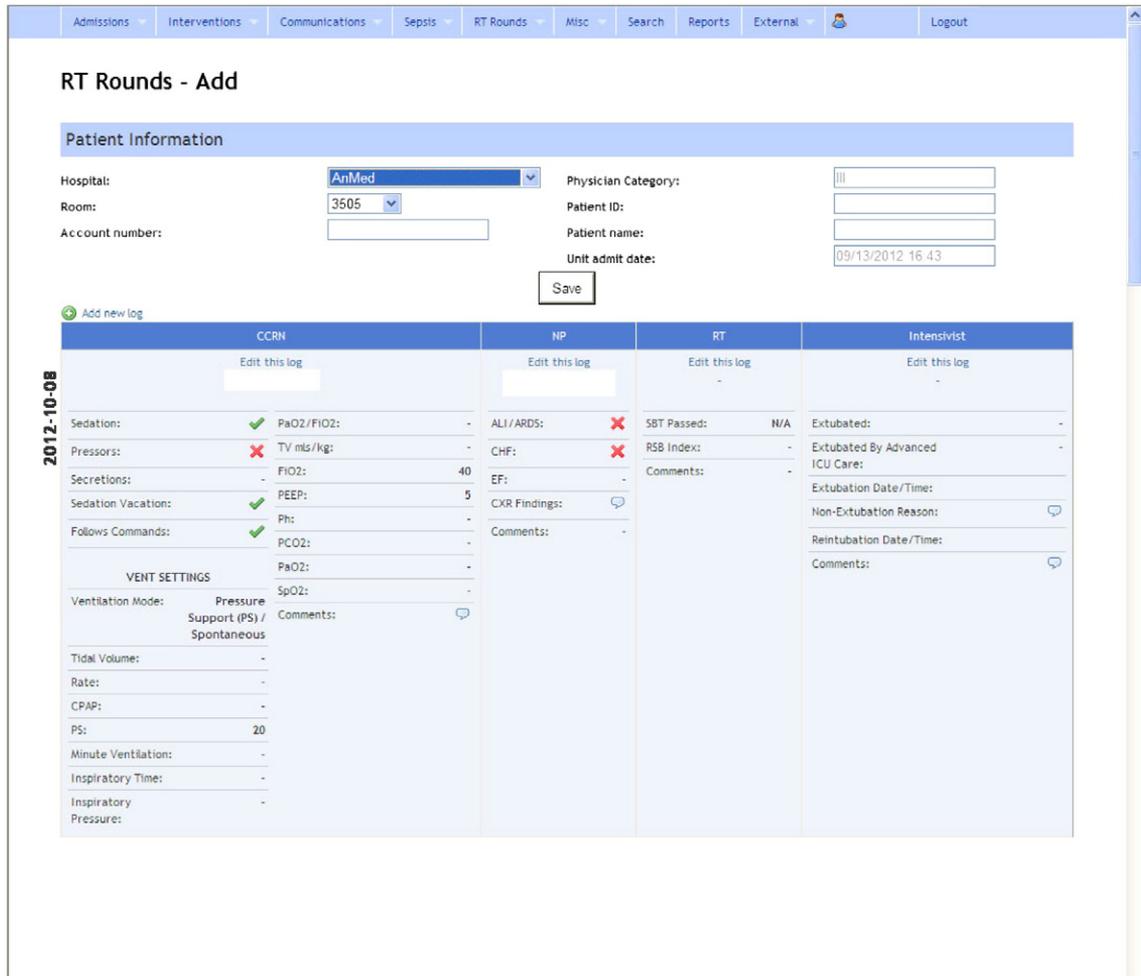


Fig. 1. Sample screen shot of online ventilator round template. Data entry was facilitated by dropdown components for each member of the “virtual team” with input from teleICU CCRN, nurse practitioner, bedside team respiratory therapist, and teleICU intensivist physician.

nursing at each intubated patient bedside, where virtual rounds were conducted. The teleICU intensivist was free to engage the participants without script or formal talking points. Decisions regarding liberation readiness and ventilator setting changes including Vt adjustments to address benchmark goals could be ordered directly by teleICU intensivist. Alternatively, based on prior agreement in some centers, the findings were treated as consultative recommendations that were then deferred to bedside practitioners for final decision making and

orders. The results of ventilator rounds were accrued in the electronic record to document whether spontaneous breathing trial and Vt adjustment or ventilator liberation were initiated during rounds.

2.4.1. Data source

This study data was entirely extracted from the eCareManager database, a proprietary database managed by Philips VISICU. All real-time monitoring entries from individual patients are collected in the

Hospital	Preimplementation Fractional adherence	2010/Q1	2010/Q2	2010/Q3	2010/Q4	2011/Q1	2011/Q2	2011/Q3	2011/Q4	2012/Q1
1	.41							.32		n/a
2	.10							.38		.56
3	.69	.67	.72	.78				.83		.85
4	.32	.48	.23	.42				.49		.46
5	.14	.14	n/a	.50				.50		.44
6	.27	.46	.33	.44	.55			.55		.53
7	.29		.33	.40	.37	.44		.47		.88
8	.42		.13	.42	.28	.24		.47		.13
9	.32			.18	.32	.42	.46	.46		.46
10	.11				.19	.19	.30	.31		.48
11	.26					.22	.28	.42	.34	.43
MEAN adherence	.34 n = 3447							.48* n = 3813		.52* n = 3271

*P < .001

P < .001

Fig. 2. “Adherence to low Vt benchmark:” cross-sectional analysis of ALI (Pao₂/Fio₂ <300) with lung protective strategy, Vt less than 7.5 mL/kg PBW. Data are presented as ratio of adherent/total number measurements; Vt/kg PBW are auto-calculated and displayed with each AGB measurement within eCareManager™ platform. Yellow highlight vertical columns represent time points for which cross-sectional analysis was conducted before and after staged implementation of ventilator rounds. Shaded horizontal entries represent proportion of adherence for each hospital over 4 Qs after implementation for and for the most recent Q analyzed 2012/Q1.

central Philips database. These data are then aggregated by Philips and reported back to the telemedicine center quarterly as mean outcome performance data for each individual ICU served by the monitoring center. Proprietary Acute Physiology and Chronic Health Evaluation (APACHE) IV regression equations are used to analyze data residing in the eCareManager database to generate individual patient outcome predictions for days of mechanical ventilation, mortality, and length of stay (LOS). The actual outcomes are compared with predicted outcomes as mortality, LOS, and ventilator days ratios for each ICU. Then, individual outcome ratios are combined to generate the mean outcome ratios.

Philips VISICU provides a Benchmark Report Users Guide to the teleICU center that provides overview, definitions, and details of the preparation methods of the data spreadsheets. Nursing and data specialist personnel at the monitoring center undergo quarterly training and supervision for data entry accuracy and completeness.

2.4.2. Definitions of reported parameters

2.4.2.1. Adherence to LPV strategy. Adherence to LPV is reported in the VISICU database in categories based on percentage of ABGs drawn at prespecified Vt ranges on patients with P/F ratios less than 300 and whether the patient had the diagnosis of ARDS. For the ARDS patients, compliance with LPV was defined by the database as less than 6.5 mL/kg PBW. For non-ARDS patients with P/F ratios less than 300, a more liberal less than 7.5 mL/kg PBW was chosen by the database as the cutoff for compliance with LPV. The cut-off definitions for compliance were stipulated by the proprietary database. Therefore, the data could not be recalculated to assign different choices for cut-off definition that match those of the recent Society of Critical Care Medicine guidelines.

For example, compliance with LPV in a non-ARDS cohort was defined as:

Compliance with LPV (non-ARDS)

$$= \frac{\text{No. of ABG drawn with ventilator} < 7.5 \frac{\text{mL}}{\text{kg}} / \text{PBW}}{\text{Total no. of ABGs drawn for that hospital}} \times 100$$

The system divides the P_{O_2} by the F_{iO_2} decimal value to arrive at the oxygenation ratio and then divides the Vt value in the ABG vent result by the PBW to obtain the calculated Vt, that is, V_t/PBW = calculated Vt in mL/kg PBW. The strategy to collect Vt data at the time of ABG allowed for a more accurate assessment of the adjustments that were made on individual patients, at least in part, as a result of ventilator rounds interventions. Thus, an individual patient who had Vt adjustment could contribute data points that were initially nonadherent but were later adjusted to adherent values. Patients whose P/F ratio improved to values more than 300 were no longer included in the analysis, although such patients might very well have continued to receive Vts that were adherent to benchmark. Data points were excluded when the height or sex was not entered and ABG results that were incompletely entered or when the value for Vt is less than 200. The system classified patients as having ARDS when they had active diagnosis categories that include ARDS chosen by the teleICU nurse in the admission note dropdown menu.

2.4.3. Ventilator duration ratio

Ventilator duration ratio is calculated as the number of days of mechanical ventilation/APACHE IV predicted days of mechanical ventilation. Therefore, cohorts of patients with VDR less than 1.0 would have been extubated before APACHE IV prediction. Alternatively, cohorts of patients with VDR more than 1.0 would have done worse than expectation. Acute Physiology and Chronic Health Evaluation IV scoring is performed on first ICU day by definition. As a result, APACHE IV predicted ratios of VDR and ICU mortality; all included patients received mechanical ventilation on APACHE IV day

1. Patients were considered ventilated by a standard routine that involved inspection of information populated within eCareManager™, including the Respiratory Flow Sheet template and the Care Plan, where dropdown pick lists include ventilated status. The timing of extubation was entered into eCareManager™ by the teleICU nurse after corroboration of the exact time of extubation with the local bedside team. The ventilator days report that is provided by VISICU shows the number of patient stays for the Q, then number of stays, where the patient was ventilated, total patient and ventilator days, and average and median ventilator days per patient. Units with fewer than 50 scored stays for the Q are not included.

During the postimplementation period, a standard for defining ventilator day changed: beginning in Q4 2011, patients with noninvasive ventilation for greater than 6 hours were added to patients counted as ventilated. Furthermore, beginning in Q4 2011, patients were considered ventilated for a “day” when they are ventilated for any fraction of a calendar day.

2.4.4. Cross-sectional and longitudinal analysis

These data from VISICU-prepared proprietary database were then used to perform cross-sectional and longitudinal comparison of end points. As depicted in Fig. 2, the preimplementation Q data from Q4 2009 were compared with the postimplementation Q (Q3 2011) that occurred after all centers had participated in at least 3 Qs of ventilator rounds, and a follow-up cross-sectional analysis was calculated for the most recent Q for which data were available for analysis (Q1 2012).

Because such before and after cross-sectional analysis may be hampered by unmeasured changes in practice across the broad implementation interval, we next performed longitudinal analysis, where we examined the individual hospital results shown here before and for the subsequent 3 Qs after the implementation for that individual hospital. Then, mean data for each Q were combined for all centers, treating the mean percentage of adherence as a continuous variable for statistical analysis.

2.4.5. Analytical methods

2.4.5.1. VDR and ICU mortality. Ventilator duration ratio and ICU mortality were reported as population means. Tests of significance to compare preimplementation and postimplementation mean values and longitudinal quarterly differences were performed by the 2-tailed Student *t* test.

2.4.6. Low Vt adherence

The determination height, sex, Vt, and calculated Vt in units milliliters per kilograms PBW were recorded automatically at the time of each blood gas analysis within eCareManager. The database reports adherence to low Vt benchmark as a binary standard, reporting percent adherence based on VISICU-defined benchmark of less than 7.5 mL/kg PBW for P/F ratio less than 300 and less than 6.5 mL/kg PBW for those patients in whom the diagnostic code for ARDS was entered into eCareManager within the first 24 hours of ICU admission. These individual determinations at each blood gas determination were then aggregated for each ICU and reported as adherent percentage of the entire ABG sample for the ICU population.

Cross-sectional analysis combined weighted means of the entire 11 hospital adherence data to perform test of significant difference by 2×2 table analysis using Fisher exact test. Test of significance for longitudinal analysis comparing quarterly mean adherence fraction were performed by 2-tailed Student *t* test.

2.4.7. Ethical issues

The ventilator rounds template remained within a dedicated server with strict protections and policy against transmission of Protected Health Information (PHI) out of patient care clinical environments. Philips VISICU is Health Insurance Portability and Accountability Act

(HIPAA)-compliant and has developed rigorous procedures for PHI, including deidentification routines that are run after the reports are created. These spreadsheets are received by the teleICU provider and passwords are protected. Data analysis specialist is certified in HIPAA compliance. All data are anonymous, stripped of all personal identification, and reported as population averages. The VISICU research consortium institutional review board waiver of individual consent was approved for this observational population-based study.

All teleICU monitoring physicians are state licensed and accredited members of the medical staff for each institution where they practice and have completed all mandated ethical conduct certification training and are certified by HIPAA training. This monitoring center is Joint Center accredited that certifies HIPAA compliance for all practitioners with annual review of policy, procedure, and audit of teleICU clinical activity.

3. Results

3.1. Low Vt adherence

In patients with P/F less than 300, percentage of adherent to Vt less than 7.5 mL/kg PBW improved from 34% to 47.5% ($P < .001$; $n = 3813$) in cross-sectional analysis after implementation of teleICU ventilator rounds, and this was sustained into the most recent Q 52% ($P < .001$; Q/2012; $n = 3272$) (Fig. 2).

Percent adherence improved in 10 of the 11 participating hospitals. We noted that the one center without improvement suspended ventilator rounds soon after implementation, although this center continued to receive quarterly benchmark reports on these measures.

By longitudinal analysis, we observed an incremental and significant improvement by the Q3 postimplementation overall from 29.5% preimplementation to 44.9% adherence by the end of a year of ventilator rounds, and this was sustained over the most recent Q (Table 1; 51.8%, $P < .003$). Furthermore, we observed no difference between centers that started ventilator rounds in early vs late implementation period.

In the subset of patients with documented ARDS/ALI on admission, Vt less than 6.5 mL/kg PBW improved from 23.3% to 37% ($P < .005$) (Fig. 3). However, ARDS/ALI as an admitting diagnosis was incompletely and inconsistently applied without a validated instrument. This was likely a result of the requirement for the teleICU admitting nurse to enter the diagnosis by dropdown menu entry to capture this clinical entity. In addition, ARDS developing after the 24 hours is not captured by this assessment by APACHE-stipulated data entry interval limited to first APACHE day. Acute respiratory distress syndrome diagnosis was more commonly applied in the postimplementation cross-sectional data collection interval. This increase appears to result from retraining and orientation of nursing staff to consensus definition and to the proper use of scroll-down diagnostic menu to designate ARDS as a diagnostic category rather than changing prevalence of ARDS during this interval.

3.1.1. Ventilator duration ratio

Mean VDR changed from 1.08 to 0.92, and this represented a significant mean –15.8% decreased after vent rounds implementation ($P < .04$) (Fig. 4). However, the baseline VDR range, 0.66 to 1.90 reflected

wide practice variation and led to a sizable standard error and non-significant change in absolute VDR. These ratios were calculated based on APACHE IV–predicted ventilator duration, which accounts for the denominator for each patient. There were no significant differences between APACHE IV scores among participating centers (mean preimplementation Q APACHE range, 47–53.3; $P =$ not significant), on the one hand nor longitudinal change in mean APACHE IV scores across all centers over the sampled cross sectional intervals (mean quarterly APACHE IV score across all centers, 51.1, 51.3, and 51.0 for preimplementation, Q3/2011 and Q1/2012, respectively; $P =$ not significant).

3.2. ICU mortality

Intensive care unit mortality ratio demonstrated longitudinal improvement that reached significance after the Q2 postimplementation (0.94 vs 0.8, 0.73, and 0.67 postimplementation) (Table 2). Because these ratios are performed using APACHE IV predictions, the mortality ratio consistently reflects the severity of illness and comorbidity characteristics of patients across the longitudinal comparison time points. Neither the ICU LOS nor the hospital mortality showed significant change during the study.

4. Discussion

This study showed that teleICU-directed ventilator rounds applied across a diverse community hospital setting were associated with a substantial and durable improvement in adherence to lung protective strategy and significant improvement in the APACHE IV–adjusted VDR as well as APACHE IV–adjusted ICU mortality ratios.

The unique feature of this process was the virtual forum designed by the teleICU service to supplement the bedside process improvement activities. This served as a semiautomated shared data entry portal that was a resource for a multidisciplinary team that consisted of the teleICU clinical team and bedside personnel. Coupled with specific workflow dedicated to ventilator management, these teleICU ventilator rounds were brought to bear on joint decision making even when all stakeholders could not regularly meet together at every bedside for this purpose.

In contradistinction to other studies of teleICU impact, this study was not a before and after comparison of the overall effect of teleICU implementation but rather was conducted well after the initiation of teleICU services. By introducing ventilator rounds in the framework of an established teleICU service relationship, the effect of this focused process improvement initiative could be detected above and beyond that of the multiple and complex dynamic changes that accompany teleICU service initiation.

Putative advantages of a teleICU ventilator rounds include a separate off-site team with a systematic focus on best practice implementation, electronic data management system that includes automated calculation of P/F ratio, PBW, and low Vt target and a shared check list for review of this information, and teleICU intensivists to convey information as well as to initiate clinical decisions at the bedside. Although we did not make any determination of time savings by bedside personnel, the compilation of ventilator mechanics data and other calculations by teleICU multidisciplinary team before conducting bedside rounds may have resulted in reduced workload by bedside team members. Inasmuch as these data facilitated ultimate decision making, the process

Table 1
Longitudinal analysis of Vt benchmark percent adherence preimplementation and postimplementation of teleICU-directed ventilator rounds

	Preimplementation	Q1 postimplementation	Q2 postimplementation	Q3 postimplementation	Q1 2012 (most recent)
Mean adherence to low Vt	29.5 ± 18.2	35.9 ± 15.8	36.9 ± 16.5	44.9 ± 15.7	51.8 ± 22.7
<i>P</i> (compared with preimplementation)		.16	.07	<.002	<.003

For longitudinal analysis, preimplementation adherence fraction is reported, followed by 3 sequential Qs and the last Q available Q1/2012. Data are reported as mean percentage adherent ± standard deviation. Tests of significance were performed by 2-tailed Student *t* test comparing mean adherence for each postimplementation Q to preimplementation mean.

Hospital	Preimplementation Fractional Adherence	2010/Q1	2010/Q2	2010/Q3	2010/Q4	2011/Q1	2011/Q2	2011/Q3	2011/Q4	2012/Q1
1	26/55							15/35		n/a
2	n/a							20/35		54/126
3	10/20							56/64		0/8
4	0/13							2/87		30/80
5	n/a							n/a		n/a
6	n/a							34/66		8/8
7	n/a							n/a		3/43
8	n/a							n/a		n/a
9	n/a							31/118		14/101
10	5/90							15/63		33/135
11	n/a							0/8		19/30
Total	41/178*							177/474		161/431
<6.5/Total ABG	23%							37%		37.3%

P = .0005 P = .0006

*Dx ARDS on day 1

Fig. 3. Cross-sectional analysis of ARDS patients recorded as adherent to benchmark less than 6.5 mL/kg PBW: ARDS diagnosis at the time of ICU admission, as designated by teleICU CCRN using dropdown menu within eCareManager admission template. n/a, no entry interval for ARDS diagnosis–designated eCareManager database.

of judging liberation readiness, Vt appropriateness, and ventilator setting adjustment needs were conducted with enhanced efficiency from the standpoint of bedside personnel time expenditure.

Although it has been reported that patients with ALI cared for in closed model ICUs are more likely to receive lower Vt and less likely to receive high Vt, in this study, the observed improvement in process and outcome was seen across ICU settings using diverse management structures [14]. The impact was similar in ICUs managed in semiclosed models with dedicated intensivist coverage as well as in ICUs using low intensity models, wherein individual practitioners did not engage in daily multidisciplinary rounds. Thus, the observed benefit of this process was not limited to those sites with a receptive team in place nor were the benefits relegated to those sites that had no preexisting bedside counterpart.

The incremental improvement in LPV adherence over time was shown to be durable. This may suggest that by the daily reiteration of this process, a modulation of potentially ingrained patterns of behavior and culture was one possible benefit of teleICU rounds. That improved adherence to benchmarks was possible across the range of low and high preperformers suggests that opportunities for successful performance improvement was available to a wide range of preexisting conditions. In addition, the incremental improvement suggests that the observed change was not the result of preimplementation meetings alone, where best practice goals were discussed and targets agreed upon because the impact of such single reinforcement meetings would be expected to dissipate with time, not to accrue benefit over the ensuing year.

The magnitude of improvement seen in this novel virtual process is consistent with previously reported bedside process improvement initiatives that dedicate additional manpower and process to efforts to improve ventilator bundle adherence. A common theme in both virtual and bedside performance improvement efforts is that daily reinforcement, method consistency, and periodic educational initiatives to reinforce principles and provide feedback to bedside providers are key components that bring successful and durable improvement in LPV and ventilator bundle adherence [15,16]. One advantage of teleICU-directed ventilator rounds in this study is the enhanced capacity to leverage scarce manpower and provide dedicated and consistent resource allocation that may not be available in all centers. In addition in supporting an iterative, reinforcement requirement, teleICU database results were shared with each center on a quarterly basis, providing the bedside practitioners with their individual center performance.

Part of the problem of examining possible teleICU effect is a lack of unified conceptual framework for this innovation. A heterogeneous group of services come under the umbrella term teleICU, although some attempt at defining these services has been made. A recent published symposium defined teleICU services as an off-site monitoring service to provide real-time bedside monitoring and bidirectional teleconferencing capability but that may offer a variety of care models and services [17]. Under this broad umbrella, teleICU programs may be further differentiated by structural, environmental, and process components. Environments may differ in size, staffing affiliation, and protocol use, and process

Hospital	Preimplementation VDR	2010/Q1	2010/Q2	2010/Q3	2010/Q4	2011/Q1	2011/Q2	2011/Q3	% change	2011/Q 3*	2012/Q1	% change
1	1.15							0.78	-32%		n/a	-
2	0.71							0.65	-8.5%		0.91	+28%
3	1.33							1.00	-24.1%		1.24	-6.7%
4	1.18							0.78	-33.9%		1.30	+10.2
5	1.90							1.30	-31.6%		0.61	-48%
6	1.23							1.24	0%		1.15	-6.4%
7	0.66							0.79	+19.6%		0.72	+9.0%
8	0.95							0.94	0%		0.83	-13%
9	1.01							0.87	-13.9%		1.08	+7%
10	0.95							0.43	-64.8%		0.82	-13%
11	0.88							1.10	+20%		0.93	+5%
MEAN VDR	1.08±.34							0.92±.28	-15.8 %		.96±.24	-3.1 %
	n = 872							n = 668			n = 804	

P = .09 P < .05 P = .37 P = .65

[* VENT DAYS reporting change 2011/Q3 to include NIPPV and fractional days as full vent day]

Fig. 4. Cross-sectional analysis of VDR: reported as VDR = ventilator duration in days/APACHE IV predicted ventilator duration in days as well as percent change in VDR (shaded column) (at cross-sectional time point in adjacent column)/preimplementation, VDR 2009/Q4.

Table 2

Intensive care unit mortality ratio (APACHE IV–adjusted) longitudinal trend before and after implementation of teleICU-directed ventilator rounds

	Preimplementation	Q1 postimplementation	Q2 postimplementation	Q3 postimplementation	Q1 2012 (most recent)
ICU mortality ratio	.94	.80	.73	.67	.65
P (compared with preimplementation)				<.04	<.03

→, Q interval is the subject heading for the designated intervals following to the right.

Intensive care unit mortality improvement after teleICU ventilator rounds: longitudinal analysis of quarterly mean ICU mortality ratio at preimplementation compared with each subsequent Q postimplementation of ventilator rounds.

models may vary from emergency intervention only to continuous and proactive engagement and involvement in best practice initiatives.

Not surprisingly, variations in teleICU practice has resulted in a broad range of putative impacts, with claims of substantial as well as no measurable impact on ICU outcome. For example, in a care model format of low intensity involvement, whereby a large fraction of bedside physicians chose to contract only for limited teleICU engagement (ie, only to intercede in cardiopulmonary arrest or ongoing emergency), the impact of teleICU services on important outcome measures such as mortality and LOS were not detected [18,19]. Conversely, it has been speculated that, in settings where high intensity 24/7 intensivist services are already in place, the additive effect of teleICU services would be substantially muted. In essence, the technological platform afforded by teleICU, such as any new technology, has variable applications and impact that appears quite sensitive to process and environment [10].

There are several limitation of this study. The retrospective-observational nature of this study does not permit direct causal association of any of the observations but rather may help support the generation of hypothesis testing studies in the future to examine which elements of the initiative, if any, could be responsible for the observed improvement in performance and outcome.

Indeed, the exposure to daily ventilator rounds may have impacted on process and outcome measures by an aggregate effect of multiple components. As an exposure, ventilator rounds were directed toward best practices including but not limited to low Vt adherence. The scope of ventilator rounds included the process of judging liberation readiness, sedation adjustments, initiation of spontaneous breathing trials, and ventilator mode and setting adjustments. Given these features, the reported improvements seen in this retrospective review cannot be attributed to any specific component of the initiative. Nevertheless, we speculate that low Vt adherence may be one of multiple factors that impacted on overall improved outcome measures. In addition, quarterly reporting to each center may have indirectly impacted on both process and outcome measures as these reports provide longitudinal feedback that reinforce the quality improvement culture and attitudes of participants.

Because the quarterly data reports used for this study were provided in a binary format of percent compliant, this did not permit analysis in this study of different cut-off points. In addition, the binary format does not permit analysis of the range or the absolute change in Vt; therefore, the magnitude of the change was not directly examined. Furthermore, the cut-off points for compliance chosen by the database do not correspond precisely to benchmark targets recently recommended by the ARDSnet and Society of Critical Care Medicine. However, despite all of these limitations, the data provide a description of altered practice patterns that demonstrates a positive improvement over the implementation timeline.

The comparison of mean groups over time does not account for changes in case mix, changing sample size, and other population parameters that may be variable and contribute to common cause variation from Q to Q [20]. To overcome this potential bias, 2 complementary analytic methods were used to examine these data. First, cross-sectional analysis at specific time points before and after all hospitals implemented ventilator rounds were used to demonstrate

change for the entire population of patients exposed to ventilator rounds. This was combined with longitudinal analysis to examine the dynamic change during individual hospital's implementation. Taken together with cross-sectional population data, this longitudinal assessment of each individual hospital's performance strengthens the hypothesis that this positive effect of ventilator rounds is temporally linked to their implementation.

However, despite the consistent improvement across all centers, these retrospective data do not fully account for possible differences in measured outcome that result from unmeasured differences that occurred over the implementation interval. To better control for such dynamic changes and to better capture the effect of the process improvement intervention, we subsequently plan to adopt process control analysis using control charts designed for this analysis. The principle advantage of using control chart methodology is to distinguish between so-called common cause variation (chance) and special cause variation (assignable). Methodology applied to process control helps account for variation such as case mix and other population changes that may vary between data collection intervals and introduce bias in the observations.

By adopting process control analysis, we hope to better clarify that the changes we detected were indeed durable and dependent on process improvement initiatives using a teleICU platform rather than a general shift in patient population or practice pattern over time.

We encountered considerable practice variation at baseline among participating centers for all process and outcome measures. For example, baseline VDR ranged from .66 up to 1.90. This underlying variability in practice pattern despite robust recommendations for best practice and published guidelines demonstrates the scope of the problem and points to the significant challenges faced by teleICU providers in a community-based setting. The lack of uniformity and resulting large standard error may limit the detection of cross-sectional differences.

In addition to these hospital-based challenges, a reporting rule change in Q4 2011 for APACHE IV altered the definition of ventilator day as any part of a calendar day as well as to include patients receiving noninvasive positive pressure ventilation. Thus, these extended inclusion criteria changed by the central database may have attenuated the magnitude of VDR reduction in the most recent Q. This diminished effect would occur because of an inclusion of more patients, and longer duration would generate a larger numerator in VDR calculation.

Moreover, one subscribing hospital included in cross-sectional analysis (hospital 1) declined to adopt structured ventilator rounds, although they continued to receive quarterly data and feedback on performance during the follow-up interval. This center's lack of improvement compared with all other centers suggests that, in the absence of daily ventilator rounds, neither preimplementation meetings nor quarterly feedback were sufficient to lead to measurable outcome differences.

In conclusion, variable practices among ICUs pose challenges to teleICU-led process improvement. Despite this, the implementation of teleICU-led ventilator rounds was associated with improved and durable adherence to LPV strategies and significant reductions in VDR and ICU mortality ratio. These data support the hypothesis that this process improvement effort contributed to the observed changes.

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