A Multi-center Study of ICU Telemedicine Reengineering of Adult Critical Care

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Dr. McLaughlin is a salaried employee and stock holder of Pfizer Inc.

Dr. Irwin has disclosed that while his institution has purchased their tele-ICU product from VISICU, now owned by Phillips Medical Systems, neither he nor anyone else has any financial relationship with the company. Dr. Irwin discloses that the review of this manuscript and the ultimate decision to publish it was made by others without his knowledge.

All other authors have no conflicts of interest to disclose.

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Abstract:	250
Text:	2,981

ABSTRACT

Background

Few studies have evaluated both the overall effect of intensive care unit (ICU) telemedicine programs and the effect of individual components of the intervention on clinical outcomes.

Methods

The effects of non-randomized ICU telemedicine interventions on crude and adjusted mortality and length of stay (LOS) were measured. Additionally, individual intervention components related to process and setting of care, were evaluated for their association with mortality and LOS.

Results

Overall, 118,990 (11,558 control; 107,432 intervention) adult patients from 56 ICUs in 32 hospitals from 19 US health care systems were included. After statistical adjustment, hospital (HR=0.84, 95%CI: 0.78-0.89, p<.001) and ICU (HR=0.74, 95%CI: 0.68-0.79, p<.001) mortality in the ICU telemedicine intervention group was significantly better than that of controls. Moreover, adjusted hospital LOS was reduced, on average, by 0.5 (95%CI: 0.4-0.5), 1.0 (95%CI: 0.7-1.3), and 3.6 (95%CI: 2.3-4.8) days, and adjusted ICU LOS was reduced by 1.1 (95%CI: 0.8-1.4), 2.5 (95%CI: 1.6-3.4), and 4.5 (95%CI: 1.5-7.2) days among those who stayed in the ICU for ≥7, ≥14, and ≥30 days, respectively. Individual components of the interventions that were associated with lower mortality and/or reduced LOS included: i) intensivist case review within 1 hour of admission, ii) timely use of performance data, iii) adherence to ICU best practices, and iv) quicker alert response times.

Conclusions

ICU telemedicine interventions, specifically interventions that increase early intensivist case involvement, improve adherence to ICU best practices, reduce response times to alarms, and encourage the use of performance data were associated with lower mortality and LOS.

INTRODUCTION

Economic factors, the patient safety movement, and humanitarian commitment to improve access to care[1] have contributed to a growing societal focus on making high-quality care more available.[2] The high costs of adult critical care[3,4] and concerns about the efficiency and sustainability of current paradigms of critical care delivery[5] demand new strategies that leverage technological advances to improve quality and access, and limit costs.[6] Intensive care unit (ICU) telemedicine is one promising technological approach that increases the availability of adult critical care services and has been shown to improve efficiency of care delivery and patient outcomes in some, but not all, studies.[7-15] In the context of critical illness, telemedicine has been defined as the provision of care to critically ill patients by remotely-located health care professionals using audio-visual communication technologies.[16] A previous study of a single health care system demonstrated that implementation of an ICU telemedicine program was associated with lower mortality and length of stay (LOS) and that part of these associations were attributable to higher rates of adherence to ICU best practices, more timely responses to alerts for physiological instability, and earlier involvement of an intensive care specialist.[15] The current study builds upon this previous research by exploring a broader range of process and setting of care metrics that content experts have previously identified to likely be i) altered by the introduction of an ICU telemedicine program and ii) associated with lower mortality and LOS.[18,19] In addition, the substantial size of this study allows insights regarding whether ICU telemedicine programs are associated with lower hospital mortality; prior studies have not had adequate power to exclude type I error. This study was designed to test whether the implementation of a multicomponent ICU telemedicine program was associated primarily with lower hospital mortality and secondarily with lower ICU mortality and shorter ICU and hospital LOS. As a secondary aim, we evaluated the relationship between individual process and setting of care factors that varied among ICU telemedicine interventions and the four main outcomes (ICU and hospital mortality and LOS).

METHODS

Study Design and Patients

This study was a nonrandomized, unblinded, pre/post assessment of ICU telemedicine interventions. Twenty-one health care systems known to be implementing an ICU telemedicine program were invited to collect patient-level data using standardized instruments. Patients were recruited from 56 participating ICUs located in 15 states representing each of the US census divisions.[17] Nineteen participating health systems enrolled patients over an average of 1,340 days (range 729-2,056). The first system started enrolling patients on May 16, 2003 and the last system enrolled the last patient on December 31, 2008. The study design, timeline, patient selection and exclusions are presented in Figure 1. Internal and external auditing demonstrated that electronic and manual methods of collection by abstractors, trained as previously described,[15] yielded similar datasets and APACHE IV scores.

Minimal enrollment targets for the control group for each ICU were designed to provide 80% power to detect a 4.5% difference in hospital mortality at a significance level of .05 and to capture a minimum of 25 deaths. A 1:10 ratio of consecutive control to intervention cases was selected based on diminishing returns of power at higher ratios. The study was also designed to have sufficient degrees of freedom to evaluate the association between mortality and LOS and 32 individual ICU telemedicine metrics related to intervention-specific changes in ICU personnel and process and setting of care. The study was conducted with prior approval of the University of Massachusetts

Human Subjects Committee (H-13346), which waived a requirement for informed consent. Participating entities provided deidentified data after local waiver of the requirement for informed consent.

ICU Telemedicine Interventions

Each ICU implemented similar technical components including audio and video connections, an ICU-focused medical record, and software for detecting evolving physiological instability (Philips, Baltimore MD). However, changes in process of care delivery, ICU admission procedures, rounding and governance structure, communication among caregivers, how performance information was used, how care was documented, how technical support was provided, and other factors varied among implementations. Data describing characteristics of each ICU, process of care, as well as structural and organizational characteristics before and after the implementation of the ICU telemedicine program were measured for each ICU using The American College of Chest Physicians ICU Telemedicine Survey instrument.[18]

Measurements

Patient-level factors including date and time of admission and discharge, vital signs and status, laboratory values, admission diagnoses, clinical disposition, geographic location, and the elements of the APACHE® IV acuity score were abstracted from electronic or hardcopy medical records as previously described and validated.[15] The 11-domain American College of Chest Physicians ICU Telemedicine Survey instrument was used (with permission) to gather information about 32 factors related to ICU personnel, process, and setting of care before and after the intervention. These measures included information about ICU type, intensivist staffing model, teaching status, ICU governance structure, use of performance information, US census region, and aspects of the ICU telemedicine support center.[18] Complete survey data from the

ICU medical director, nurse manager, or both was obtained using electronic survey delivery for each of the 56 ICUs that participated in this study.

Statistical Analyses

Hazard ratio (ICU telemedicine intervention *vs.* control) for dying in the hospital was pre-specified as the primary study outcome. Secondary outcomes included ICU mortality and hospital and ICU LOS. Descriptive statistics were derived for continuous variables and univariate comparisons between groups for continuous outcomes were made using the Mann Whitney U or the Student's t test. Comparisons between groups for categorical variables were made using Fisher's Exact or Chi-squared tests.

Both crude and adjusted Cox proportional hazards regression models were constructed to evaluate the effects of the ICU telemedicine interventions on hospital and ICU mortality. For Cox regression analyses, likelihood ratio Chi-squared tests were used to determine improved statistical fit. The proportional hazards assumption was tested for all Cox models. Any meaningful, statistically significant interaction terms or appreciable confounders remained in final parsimonious models. Confirmatory analyses using logistic regression were also performed.[19] The statistical modeling, survey domains, and composite scores are described and detailed in the on line supplement.

All p-values were calculated using two-sided tests and values $\leq .05$ were considered statistically significant. All statistical analyses were conducted using SAS version 9.2 (Cary, NC) and STATA version 10 (College Station, TX).

RESULTS

Of 21 health care systems that collected data, 19 submitted patient-level deidentified datasets for pre-specified analyses. Participating ICUs (n=56) were geographically dispersed across 15 US states; 8 (14%) ICUs were located in the Northeast; 28 (50%) in the Midwest; 8 (14%) in the South; and 12 (21%) ICUs were in the West US census region. Participating ICUs were from 38 hospitals that ranged in size from 88 to 834 licensed beds that were part of 19 healthcare systems. Seven (13%), 17 (30%), and 32 (57%) ICUs served rural, suburban, and urban populations, respectively. Nine (16%) ICUs served populations <100,000, 36 (64%) served populations of 100,000-999,999, and 11 (20%) served populations ≥1 million. A broad spectrum of adult ICU types was included: 27 (48%) mixed medical-surgical ICUs, 9 (16%) medical ICUs, 8 (14%) surgical ICUs, 6 (11%) coronary care units, 4 (7%) neuroscience ICUs, and 2 (4%) cardiothoracic ICUs. Twenty-one (38%) ICUs were non-teaching, 20 (36%) were teaching hospitals but unaffiliated with a university or academic medical center, and 15 (27%) were affiliated with a major academic medical center or university.

A total of 118,990 adults that had a valid ICU admission event as defined by the APACHE IV methodology were identified from 119,169 records (Figure 1). Comparison of 11,558 control with 107,432 ICU telemedicine group patients revealed that ICU telemedicine group patients had significantly higher APACHE IV acuity scores and predicted mortality, had a larger proportion of medical primary admission diagnoses, were less likely to have been admitted from an operating room, and had a significantly different distribution of primary admission diagnoses (Table 1).

Overall, 11,907 or 10% of the patients died in the hospital. Unadjusted analyses revealed that a significantly higher proportion of control group patients (1,242/11,558;

11%) than intervention group patients (10,665/107,432; 10% intervention, p<.01) died in the hospital over a median follow-up of 6.2 days (range 1 hour to 880 days). Similarly, 7,134 (6%) of patients died in the ICU. A significantly larger proportion of control group patients (901/11,558; 8%) died in the ICU than ICU telemedicine group patients (6,233/107,432; 6%; p<.01) over a median follow up of 1.9 days (range 1 hour to 383 days). Survival analyses, that adjusted for relevant covariates, revealed significantly lower hospital and ICU hazard ratios for patients in the ICU telemedicine group compared to the control group (adjusted hospital mortality: HR=0.84, 95%CI: 0.78-0.89, p<.001; adjusted ICU mortality: HR=0.74, 95%CI: 0.68-0.79, p<.001; Figure 2). There was no evidence of violation of the proportional hazards assumption. Confirmatory analyses using logistic regression yielded similar results.[19]

Hospital and ICU LOS were significantly shorter for ICU telemedicine intervention patients. After adjustment, ICU LOS for ICU telemedicine intervention patients was 20% shorter (95%CI: 19 to 22%; p <.001) and hospital LOS was 15% shorter (95%CI: 14 to 17%; p <.001) compared to controls (Figure 3). In addition, crude and adjusted analyses revealed that the effect of the ICU telemedicine intervention on changes for hospital and ICU LOS depended on how long the patient stayed. Specifically, the effectiveness of the interventions for reducing LOS was clinically meaningful only among patients who remained in the hospital for at least one week (p for interaction <.01). Adjusted hospital LOS was reduced, on average, by 0.5 (95%CI: 0.4-0.5), 1.0 (95%CI: 0.7-1.3), and 3.6 (95%CI: 2.3-4.8) days among those who stayed in the hospital for ≥7, ≥14, and ≥30 days, respectively (Figure 3). Similarly, adjusted ICU LOS was reduced, on average, by 1.1 (95%CI: 0.8-1.4), 2.5 (95%CI: 1.6-3.4), and 4.5 (95%CI: 1.5-7.2) days among those who stayed in the ICU for ≥7, ≥14, and ≥30 days, respectively (Figure 3A).

In addition to identifying the overall effects of implementing an ICU telemedicine program on mortality and LOS, we examined the effect of each of the 11 ICU-telemedicine survey domains.[18] Adjusted analyses revealed that changes in the ICU characteristics domain (OR=0.70, 95%CI: 0.56-0.87; p<.01), physician leadership domain (OR=0.80, 95%CI: 0.70-0.92; p<.01), and best practices and performance review domain (OR=0.82, 95%CI: 0.71-0.95, p<.01) were associated with significant reductions in hospital mortality, whereas only changes in the ICU characteristics (OR=0.71, 95%CI: 0.56-0.91; p<.01) and the physician leadership domains (OR=0.74, 95%CI: 0.64-0.86; p<.001) were associated with significant reductions of ICU mortality. Changes in the ICU telemedicine experience domain (OR=0.89, 95%CI: 0.81-0.97; p<.01) were associated with reduced hospital LOS, and changes in the integration and teamwork domain (OR=0.95, 95%CI: 0.91-0.99; p=.01) were associated with reduced ICU LOS.

Individual survey items that accounted for ≥15% change in domain scores that were significantly associated with any of the four outcomes were i) higher frequency of intensivist case review within one hour of ICU admission, ii) more frequent review of performance data with hospital leadership, iii) higher levels of adherence to ICU best practices, iv) more rapid responses to alerts and alarms, v) more frequent interdisciplinary rounds, and vi) more effective ICU committee as judged by ICU clinical leaders. Community characteristics, hospital size, teaching status, region, and intensivist staffing model were not significantly related to ICU or hospital mortality or LOS.

We found that composite scores (derived from important survey items) demonstrated significant step-wise relationships with all four outcomes (Figure 4).

DISCUSSION

The main finding of this study was that implementation of an ICU telemedicine program was associated with significantly lower mortality and shorter LOS in both the ICU and hospital setting. Significantly reduced hospital and ICU mortality and LOS were found in both crude analyses and analyses that were adjusted for potential confounding factors including differences in acuity score, operative status, effects of time alone, and primary admission diagnosis. The association of the ICU telemedicine interventions with lower hospital mortality is notable because prior studies have not had adequate power to provide unequivocal evidence of this association. Notably, the reduction in LOS attributed to the ICU telemedicine intervention was most clinically meaningful among patients who stayed in the hospital or ICU for at least one week. The large size of the study and its finding that improvements in performance were not limited to a single type of ICU, size of hospital or community served, hospital teaching status, or US region suggests that these findings are broadly, rather than narrowly, applicable. Adult critical care therapeutic interventions that reduce mortality among high acuity patients are generally associated with increased LOS due to the longer recovery times.[20] The combination of lower mortality with decreased LOS suggests that ICU teams that are supported by a telemedicine program more quickly stabilize patients and facilitate recovery to discharge leading to an overall reduction in mortality, facilitate earlier transition to rehabilitative care, or more efficiently transition patients that will die in the hospital to comfort only care. Incorporating intervention components centered around prevention—including higher levels of adherence to ICU best practices and quicker response times to alerts and alarms—were related to improved outcomes, supporting the notion that instilling a substantial preventive component in ICU-telemedicine programs is key.

In addition to demonstrating that the overall ICU telemedicine intervention was associated with significantly reduced mortality and LOS in both adjusted and unadjusted analyses, we identified individual ICU process and setting of care domains that were significantly associated with an improvement in at least one of the four major outcomes.

To provide a more granular view of which changes in processes were associated with improved outcomes, we also identified six individual survey items that drove the differences in domain scores. First, having an intensivist perform a workstation-assisted review of the care plan within 1 hour of patient admission was identified as a driving item for the survey domains that were significantly associated with all four study outcomes. Second, having more frequent collaborative review and use of performance data was associated with lower mortality and LOS, consistent with the quality improvement tenet that how performance information is used is more important than the availability of reports.[21] Third, implementation-related increases in rates of adherence to ICU best practices were associated with lower mortality and LOS, confirming our previous findings.[15] Fourth, shorter response times for laboratory value alerts and alarms for physiological instability were associated with shorter ICU LOS, consistent with prior patient safety studies.[15,22,23] Fifth and sixth, like previous studies,[24] interdisciplinary rounds and institutional ICU committee effectiveness were associated with lower adjusted mortality. The identification of these six, specific ICU process improvement elements may help ICUs with limited resources identify where best to focus their quality improvement efforts.

Notably, however, the individual impact of these six distinct survey items on study outcomes was small. Instead, individual survey items appeared to have additive effects as demonstrated by the larger overall effects of the domains and composite scores. One interpretation is that impact of an ICU telemedicine program is related more to the breadth of change of key ICU care processes rather than any one factor, and that improvements in key ICU processes are additive with respect to their association with clinically important health outcomes.

Interestingly, ICU physician staffing model was not a significant predictor of any of the outcomes. Taken together previously inconclusive studies,[25,26] findings from this study suggest that it is not the on-site presence of an intensivist that drives better outcomes, rather it is when and how that individual is engaged in case management. Engagement using telemedicine tools was associated with reduced ICU and hospital mortality and LOS for both high-intensity and low-intensity staffing models.

Identifying both domains and individual components of the broader ICU telemedicine intervention that were associated with improved outcomes helps to resolve previous concerns raised by systematic reviews and meta-analyses that the associations of ICU telemedicine programs with lower mortality and/or LOS are due only to unknown factors or chance alone.[27,28] Implementation of ICU telemedicine programs, to date, have improved mortality and LOS by improving the timeliness of access to intensivist case management, encouraging the effective use of performance information, facilitating ICU best practice adherence, increasing interdisciplinary rounding, improving ICU committee effectiveness, and other factors.[29]

The findings of this study should be interpreted in the context of its limitations. The sample of hospitals and ICUs was not a random sample from the United States; instead, the 19 geographically and demographically diverse sites were self-selected based on willingness to invest in care improvement. Furthermore, although this study controlled for a wealth of clinical, demographic, and process and setting of care factors, the nonrandomized pre/post study design does not provide robust protection against bias introduced by unmeasured confounders or the effects of time alone. We performed extensive analyses to identify time-related changes that would indicate the improvements we observed would have occurred in the absence of the telemedicine intervention. Analyses that included of a variety of sequence of enrollment or time factors in our models did not materially alter results, and we included a representative time of enrolment factor in our final models. Time-stratified analyses also identified changes in outcomes that corresponded to the time of intervention. Finally, because the validated instrument that we used to measure process and setting of care variables did not explain all of the variance that we observed in the outcomes, it is possible that some important predictive factors were not included or unaccounted for effects of time may be present.

Despite these limitations, this study demonstrated that implementation of an ICU telemedicine program by 56 ICUs across 19 diverse US health care systems was associated with meaningfully decreased mortality and LOS in both adjusted and unadjusted analyses. Improved outcomes were primarily attributable to earlier intensivist management, coordinated timely usage of performance information, achievement of higher rates of adherence to best practices, shorter alarm response times, more frequent interdisciplinary rounds, and a more effective ICU committee. Moreover, although each of these components had small, independent effects on mortality and LOS, their effects were additive, suggesting that breadth of change in these key ICU care processes is more important than any single factor.

Acknowledgements:

Author Contributions: Craig M. Lilly, MD had full access to the data and takes responsibility for its integrity and the accuracy of the analyses. *Study Concept and Design*: Lilly, McLaughlin, Baker, Zhao, Irwin. *Acquisition of data*: Lilly, Cody, Landry, Zhao. *Analysis and interpretation of the data*: Lilly, McLaughlin, Zhao, Baker, Irwin.

Conflicts of interest: Dr. John M. McLaughlin is an employee of Pfizer Inc. The UMass authors are in strict compliance with the University of Massachusetts conflict of interest policies and accordingly have not accepted anything of value from any commercial entity.

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Table 1. Patient Characteristics.

Characteristic	Control Group (n=11,558)	ICU Telemedicine Group (n=107,432)	p value
Age (years ± SD)	62.7 ± 17.6	62.7 ± 17.4	.81
Male sex n, (%)	6261 (54.2)	58192 (54.2)	.46
APACHE IV score (mean ± SD)	47.4 ± 25.7	52.5 ± 24.7	<.001
APS Score (mean ± SD)	35.4 ± 23.1	40.8 ± 22.6	<.001
Post operative case n, (%)	2818 (24.4)	23073 (22.0)	<.001
Primary Admission Diagnosis n, (%)			
Sepsis	1,899 (15.6%)	17,302 (16.5%)	<.001
Respiratory Failure	590 (5.1%)	7,192 (6.8%)	
Unstable Angina	427 (3.7%)	6,929 (6.6%)	
GI Bleeding	548 (4.7%)	5,984 (5.5%)	
Acute Myocardial Infarction	685 (5.9%)	4,385 (4.2%)	
Congestive Heart Failure	371 (3.2%)	3,028 (2.9%)	
Cerebral Vascular Accident	293 (2.5%)	2,890 (2.8%)	
Coronary Artery Bypass	249 (2.2%)	2,569 (2.4%)	
Diabetic Ketoacidosis	245 (2.1%)	2,154 (2.0%)	
COPD Exacerbation	219 (1.9)	999 (0.9%)	

Figure Legends

Figure 1 Study timeline, case selection, and availability of acuity scores.

Figure 2 (A). Adjusted ICU- (left) and hospital- (right) specific survival estimated by Cox proportional hazards regression[†] and by healthcare system (B). [‡]

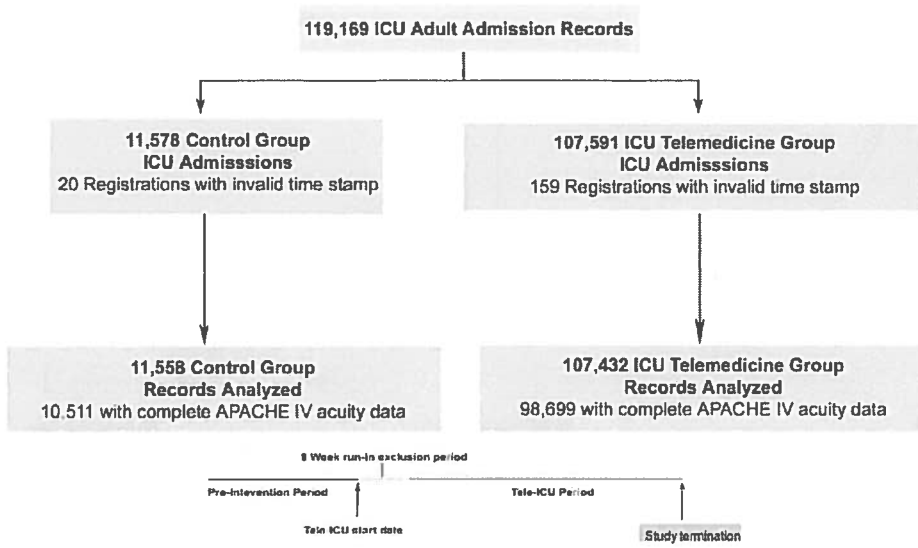
[†]Models adjusted for APACHE IV score, age, hospital or ICU identifier (as a random effect), admission source, primary admission diagnosis, operative status, time from start of study enrolment, heart rate, admission and highest creatinine values, respiratory rate, admission hematocrit, blood urea nitrogen (BUN), white blood cell count (WBC), Glasgow Coma Score, prothrombin time (PT), anion gap, urine output (in the first 24 hours), base excess, total bilirubin, and albumin value. [‡]The center of the diamond represents the effect estimate, the bars represent 95% confidence intervals, the symbol size is proportional to the number of observations for the corresponding healthcare system and the overall effects are presented as diamonds in the bottom row. HR is hazard ratio and CI is confidence interval.

Figure 3 (A). Changes in ICU (left) and hospital (right) LOS attributable to the ICU telemedicine interventions by duration of stay. The magnitude of the effects of the ICU telemedicine interventions on length of stay (LOS) increased with duration of stay. Intervention effects were statistically significant for both short and long stay patients but clinically important only for the groups with longer stays.

* p-values < .01 in adjusted models for the LOS of the ICU telemedicine group compared to the control group. Figure 3 (B). Percent change in ICU (left) and hospital (right) LOS as a function of healthcare system. The center of the diamond represents the effect estimate with the bars representing 95% confidence intervals. The size of each symbol is proportional to the number of observations for the corresponding healthcare system. Overall effects are presented as diamonds in the bottom row.

Figure 4. Relationship between Composite ACCP ICU Telemedicine Survey Score and ICU (left) and Hospital (right) Mortality and LOS *

*Individual survey items that accounted for the changes in each domain score that was significantly associated with each outcome were identified. A three-component composite score was created that included i) the change (after-before) in all individual survey items contributing to 15% of more of the observed change in domain score, ii) a three-point increase for ICUs in the top decile (because they could not improve), and iii) a three-point decrease for ICUs in the bottom decile of item response (because they did not improve).



Study timeline, case selection, and availability of acuity scores.
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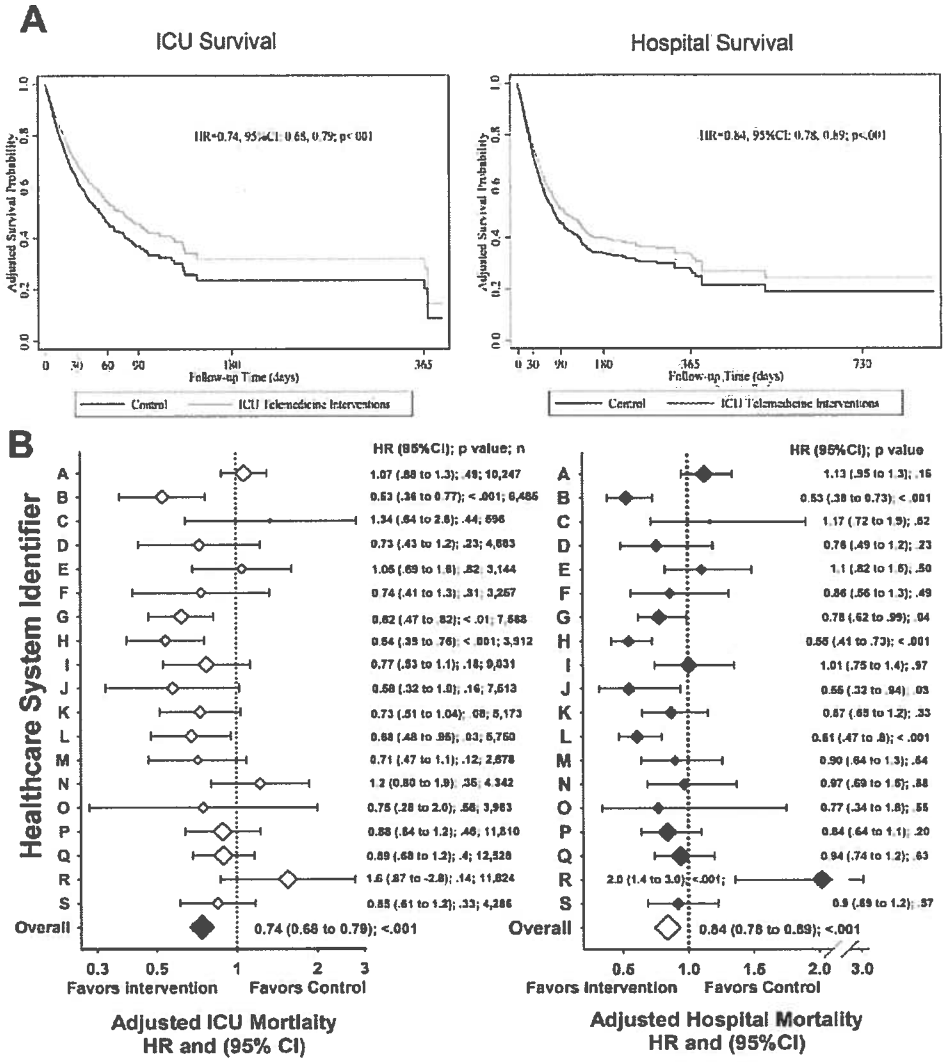

Figure 2 (A). Adjusted ICU- (left) and hospital- (right) specific survival estimated by Cox proportional hazards regression† and by healthcare system (B). ‡

†Models adjusted for APACHE IV score, age, hospital or ICU identifier (as a random effect), admission source, primary admission diagnosis, operative status, time from start of study enrolment, heart rate, admission and highest creatinine values, respiratory rate, admission hematocrit, blood urea nitrogen (BUN), white blood cell count (WBC), Glasgow Coma Score, PT anion gap, urine output (in the first 24 hours), base excess, total bilirubin, and albumin value. ‡The center of the diamond represents the effect estimate, the bars represent 95% confidence intervals, the symbol size is proportional to the number of observations for the corresponding healthcare system and the overall effects are presented as diamonds in the bottom row. HR is hazard ratio and CI is confidence interval.

215x241mm (300 x 300 DPI)

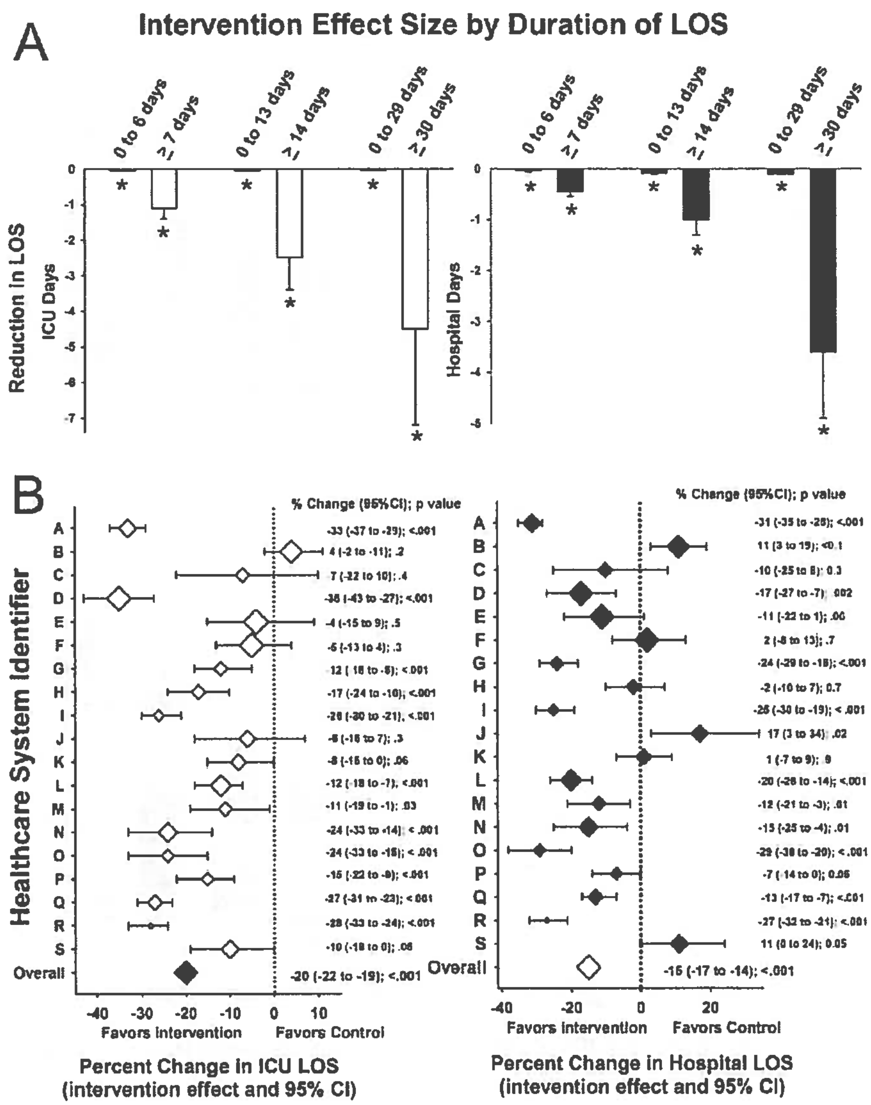

Figure 3 (A). Changes in ICU (left) and hospital (right) LOS attributable to the ICU telemedicine interventions by duration of stay. The magnitude of the effects of the ICU telemedicine interventions on length of stay (LOS) increased with duration of stay. Intervention effects were statistically significant for both short and long stay patients but clinically important only for the groups with longer stays. * p-values < .01 in adjusted models for the LOS of the ICU telemedicine group compared to the control group. Figure 3 (B). Percent change in ICU (left) and hospital (right) LOS as a function of healthcare system. The center of the diamond represents the effect estimate with the bars representing 95% confidence intervals. The size of each symbol is proportional to the number of observations for the corresponding healthcare system. Overall effects are presented as diamonds in the bottom row.

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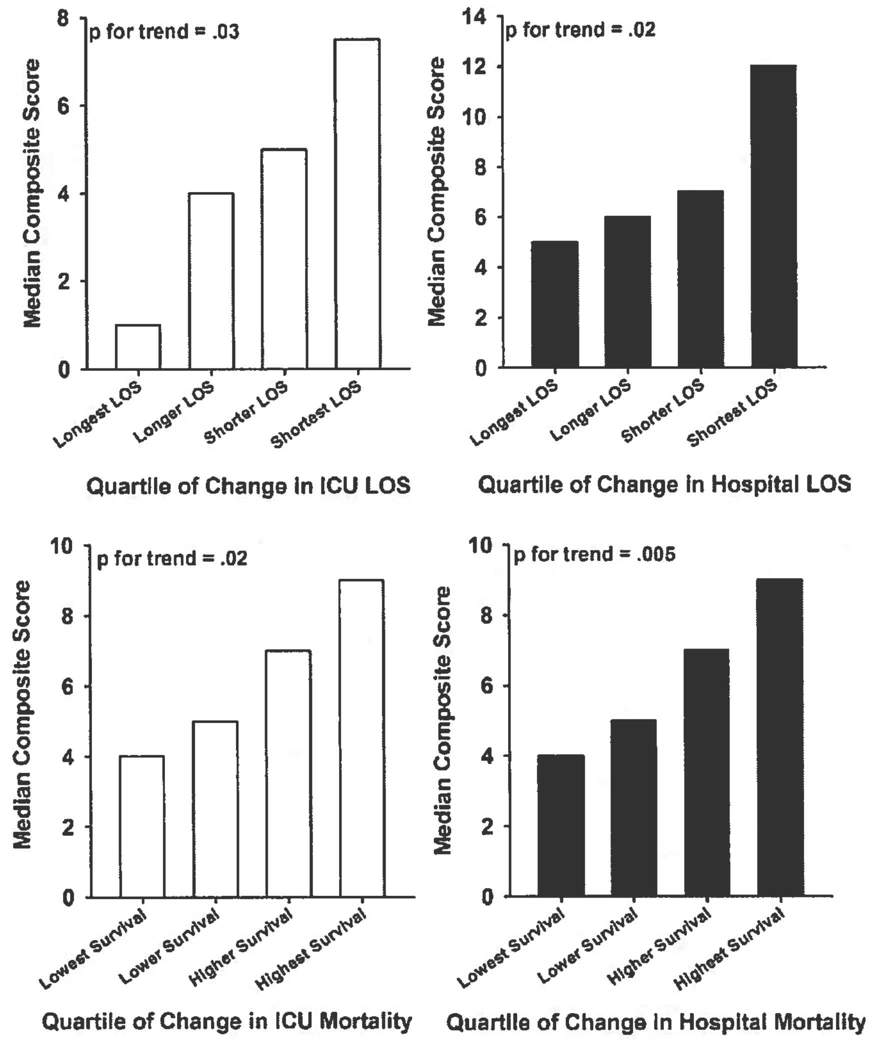

Figure 4. Relationship between Composite ACCP ICU Telemedicine Survey Score and ICU (left) and Hospital (right) Mortality and LOS *

*Individual survey items that accounted for the changes in each domain score that was significantly associated with each outcome were identified. A three-component composite score was created that included i) the change (after-before) in all individual survey items contributing to 15% of more of the observed change in domain score, ii) a three-point increase for ICUs in the top decile (because they could not improve), and iii) a three-point decrease for ICUs in the bottom decile of item response (because they did not improve).
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On Line Supplement

Descriptions of Models

LOS was modeled continuously using general linear mixed models (GLMM) [1] using restricted estimation by maximum likelihood (REML). For continuous outcomes, type 3 F-tests of effects were used to evaluate the significance of the contribution of predictors to each model and the minimum deviance was used to select the best overall fitting models. Because LOS data were largely skewed, log-transformation of LOS outcomes was necessary before analysis using GLMM to meet the assumptions of residual error normality and linear response.

Factors assessed for inclusion in all adjusted models were APACHE IV score, age, ICU or healthcare system identifier (as a random effect), admission source, primary admission diagnosis, operative status, time from start of enrollment, heart rate, admission and highest creatinine values, respiratory rate, admission hematocrit, blood urea nitrogen (BUN), white blood cell count (WBC), Glasgow Coma Score, prothrombin time (PT), anion gap, urine output (in the first 24 hours), base excess, total bilirubin, and albumin value. The effect of time of enrollment was adjusted for by including a time of enrollment factor and assessed using stratified analyses.

Survey Domains

The 11 domains of the ICU telemedicine survey instrument were calculated using responses from before and after program implementation for each ICU. Changes in these domain scores were used as explanatory variables in logistic regression models predicting whether hospital and ICU mortality and LOS were significantly reduced (ICUs that improved *vs* those that did not). To increase precision, final parsimonious models were constructed that included only domains that: i) were statistically significant at $p<.0125$ (with Bonferroni adjustment for four tests), ii) improved the precision of the estimated domain parameters, or iii) changed the model parameters for a domain by at least 10% (i.e., confounded).

Survey Composite Score

Finally, to better characterize the models, individual survey items that accounted for substantial changes in the domain scores were used to construct a composite score. This composite score had three components: i) the change (after-before) in all individual survey items contributing to 15% or more of the observed change in the overall domain score, ii) a three-point increase for ICUs that started in in the top decile of item response (because they could not improve), and iii) a three-point decrease for ICUs in the bottom decile (because they did not improve). Survey items were designed such that a one-unit change indicated a clinically relevant difference in process or setting of care.[2]

References

1 McLean RA SW, Stroup WW. . A unified approach to mixed linear models. American Statistician 1991; 45:54-64

2 Lilly CM, Fisher KA, Ries M, et al. A national ICU telemedicine survey: validation and results. Chest 2012; 142:40-47