Intensive care unit telemedicine: Alternate paradigm for providing continuous intensivist care

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Objective: **Intensive care units (ICUs) account for an increasing percentage of hospital admissions and resource consumption. Adverse events are common in ICU patients and contribute to high mortality rates and costs. Although evidence demonstrates reduced complications and mortality when intensivists manage ICU patients, a dramatic national shortage of these specialists precludes most hospitals from implementing an around-the-clock, on-site intensivist care model. Alternate strategies are needed to bring expertise and proactive, continuous care to the critically ill. We evaluated the feasibility of using telemedicine as a means of achieving 24-hr intensivist oversight and improved clinical outcomes.**

Design: **Observational time series triple cohort study.**

Setting: **A ten-bed surgical ICU in an academic-affiliated community hospital.**

Patients: **All patients whose entire ICU stay occurred within the study periods.**

Interventions: **A 16-wk program of continuous intensivist oversight was instituted in a surgical ICU, where before the intervention, intensivist consultation was available but there were no on-site intensivists. Intensivists provided management during the intervention using remote monitoring methodologies (video conferencing and computer-based data transmission) to obtain clinical information and to communicate with on-site personnel. To assess the benefit of the remote management program, clinical and economic performance during the intervention were compared with two 16-wk periods within the year before the intervention.**

Measurements and Main Results: **ICU and hospital mortality (observed and Acute Physiology and Chronic Health Evaluation III, severity-adjusted), ICU complications, ICU and hospital length-of-stay, and ICU and hospital costs were measured during the 3 study periods. Severity-adjusted ICU mortality decreased during the intervention period by 68% and 46%, compared with baseline periods one and two, respectively. Severity-adjusted hospital mortality decreased by 33% and 30%, and the incidence of ICU complications was decreased by 44% and 50%. ICU length of stay decreased by 34% and 30%, and ICU costs decreased by 33% and 36%, respectively. The cost savings were associated with a lower incidence of complications.**

Conclusions: **Technology-enabled remote care can be used to provide continuous ICU patient management and to achieve improved clinical and economic outcomes. This intervention's success suggests that remote care programs may provide a means of improving quality of care and reducing costs when on-site intensivist coverage is not available. (Crit Care Med 2000; 28: 3925–3931)**

Key Words: telemedicine; critical care; complications; medical errors; intensivists; monitoring; medical economics; e-health care; remote care; remote monitoring

Intensive care units (ICUs) account for ~10% of inpatient acute care beds (1, 2), and this proportion is expected to increase substantially during the next two decades. Aggregate mortality in U.S. ICUs is estimated at 8% to 10% (3), or 400,000-500,000 patients annually. Avoidable adverse events occur frequently in ICU patients and contribute to adverse outcomes (4–6). Despite numerous studies demonstrating improved clinical outcomes when ICUs are staffed by full-time intensivists (7–15), a variety of different care models exist in U.S. ICUs. Commonly cited reasons that most U.S. hospitals do not have dedicated intensivists include concerns about costs, practice preferences, and a shortage of ICU physicians. The shortage of intensivists is particularly problematic (16) and will worsen as the U.S. population ages (17, 18). Alternative care models are needed to provide the highest quality care to a rapidly expanding ICU patient population.

For years, telemedicine technologies have enabled off-site physicians to provide quality ambulatory health care to patients in remote locations (19–22). Recent advances in video conferencing and high bandwidth data transmission led us to hypothesize that telemedicine could be extended to inpatient care and provide a means for intensivists to receive clinical data and interact with on-site caregivers.

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Remote ICU care might leverage intensivists over multiple ICUs, thereby improving patient access to expert critical care. The present study evaluated the feasibility of remote ICU management by evaluating whether instituting 24-hr remote management of ICU patients by trained intensivists would improve clinical outcomes and reduce costs in an ICU without continuous on-site intensivist care.

MATERIALS AND METHODS

Study Design. We conducted an observational study with two retrospective baseline periods and a prospective intervention period. The study was approved by the Johns Hopkins Medical Institution's Joint Committee on Clinical Investigation. Healthcare Interchange, of St. Louis, MO, provided Telemedical equipment.

Study Population. The study site was a surgical ICU in a 450-bed, academic-affiliated hospital. The study intensivists provided patient care exclusively from their homes. Cameras and data transmission equipment used for remote care were installed in the ICU and the intensivists' homes.

All patients whose entire ICU stay occurred within the study periods were included, unless they met predefined exclusion criteria, including the following: age, <16 yrs; ICU stay, <4 hrs; transfer from the study ICU to another hospital; and missing Acute Physiology and Chronic Health Evaluation (APACHE) III data elements.

The ten-bed study ICU cares for a variety of elective and emergency surgical and trauma patients but not cardiac or transplant surgery patients. The surgical ICU during the baseline periods was an open-unit model without on-site ICU physician staff directly responsible for patient care. A board-certified critical care surgeon reviewed all patients' charts each day to assist with triage issues. In addition, this individual made recommendations if clinical issues were not adequately addressed by the primary care team. For select patients, the intensivist participated in the care process either as a consultant (~30% of patients) or as a critical care physician providing management services (5% to 10% of patients). Routine ICU care was provided by surgical attending physicians and Johns Hopkins Hospital surgical house staff who were not assigned to the ICU. Nurse/patient ratios were 1:1 and 1:2 during both the baseline and intervention periods. There was no computerized bedside record. There were no new critical pathways or practice guidelines introduced during the study period. A separate neurologic ICU opened between the two baseline periods, resulting in fewer neurosurgical patients in the ICU during the later two study periods.

Study Periods. The intervention lasted for 16 wks (September 1, 1997, through December 18, 1997). Two baseline periods of equal duration were used for comparison of clinical and economic outcomes. The first was selected to control for seasonal variations (September 1, 1996, to December 18, 1996); the second was selected to evaluate possible time-related changes in outcomes (February 1, 1997, through May 18, 1997).

Intervention. During the intervention period, one of four intensivists (BAR, TD, PP, MJB) provided round-the-clock monitoring of all ICU patients from their home. Intensivists and Healthcare Interchange personnel trained on-site caregivers during a 2-wk period before the intervention began. Intensivists interacted with patients and hospital personnel and accessed clinical data via dedicated, computer-based video conferencing and data transmission equipment. Video conferencing equipment enabled direct visualization of patients and staff and communication with on-site caregivers. Bedside monitoring data were transmitted in real-time via a telephone access system (Spacelabs Medical, Seattle, WA). Electrocardiograms, radiographs, consultant notes, and bedside data flowsheets were scanned and transmitted digitally. Laboratory data were accessed through a telephone terminal-emulation system.

On each day, one of the four intensivists was responsible for management of the ICU patients at the study site for that 24-hr period. At the start of the day, the intensivist reviewed all available clinical information for each patient and formulated a care plan in conjunction with the on-site physicians (attending and house staff). Formal video conferencing "rounds" occurred on ~50% of the days. When formal rounds were not possible because of competing priorities, the intensivists discussed each case with a senior member of the house staff or attending staff. Available clinical data, including stored bedside monitor of physiologic data, were reviewed at regular intervals throughout the day. The frequency of this review process depended on the acuity of the patient but usually was performed at least every 2 hrs, except from approximately midnight until 6 am. From midnight until 6 am, the intensivists attempted to sleep and were contacted by on-site personnel, as needed. Twice a day, the intensivists discussed each patient with the bedside nurse. In addition to these regular activities, intensivists were reached by beeper when necessary and contacted on-site personnel when their review of patient data suggested the need for further information or therapy. The intensivists initiated the majority of the contact between the intensivists and the ICU. Intensivists were notified of new admissions, were contacted for emergencies, and were beeped when on-site personnel desired assistance or advice. Calls from the house staff and nursing staff came at all hours of the day and night. House staff did not call for minor interventions or for routine catheter changes. Remote intensivists kept a log of the time devoted to clinical care, which averaged 4–5 hrs per day. Study intensivists never came to the hospital to care for patients.

The surgical team retained primary responsibility, but remote intensivists had clinical privileges at the hospital and wrote orders. House staff, primary care physicians, and other on-site personnel (e.g., anesthesiologists) responded physically to emergencies and performed all procedures. Surgical staff continued to bill for procedures and other professional services during the intervention period. House staff were supervised by study intensivists, who were responsible for communicating key information to the attending physician. Attending physicians could overrule the intensivist in the event of disagreement regarding patient management. Remote intensivists did not have the authority to admit or discharge patients.

Data Acquisition. An independent group (Quality of Care Research-Johns Hopkins University) abstracted charts from all study patients for APACHE III, outcome, and cost data.

APACHE III data from the first ICU day were compared with the national APACHE III database to determine the predicted risk of ICU and inhospital death and the predicted ICU and hospital length-of-stay (LOS) for each patient. Measured outcome data included ICU complications, ICU and hospital mortality, and ICU and hospital LOS. LOS data were calculated based on actual hours per 24 hrs. However, APACHE software calculates LOS based on the presence in the hospital (or ICU) on a given calendar day. Measured ICU complications were chosen and defined prospectively (Appendix) and included myocardial infarction, cardiac arrest, reintubation, pulmonary failure, acute renal failure, gastrointestinal bleeding, sepsis, and ICU readmission.

Cost data were obtained for each patient from hospital billing information and included both inpatient and physician costs. The methods developed by Lave et al. (23) were used to convert hospital and physician charges to costs, except that the Maryland Health Services Cost Review Committee's cost/charge ratio for the study hospital (0.785) (24), rather than the less accurate Medicare rate, was used. Physician billing data included charges, Current Procedural Terminology (CPT) codes, and amount paid. Costs for each CPT encounter were calculated using the RBRVS (resource-based relative value scale) (25). When CPT codes were not listed in the RBRVS file, the amount paid was used (3% of encounters). To adjust for inflation, all costs for 1997 were deflated using the Consumer Price Index for Medical Care, with 1996 serving as the base year (26).

Intervention costs were classified as physician costs; these included personnel, hardware, and communication charges. Personnel costs were calculated by multiplying intensivist salary costs (including 29% fringe benefits) by the percent of their time devoted to remote ICU patient care. Hardware cost data were provided by Healthcare Interchange; equipment costs were depreciated over 3 yrs. Healthcare Interchange personnel costs (installation, maintenance, repair) were not tracked and are not included. Communication charges include line installation fees and monthly charges. Individual patient costs related to the telemedicine intervention were calculated by multiplying daily costs (total intervention cost divided by patient days) by LOS.

Data Analysis. A descriptive analysis was performed on the primary outcome variables: ICU and hospital mortality; ICU and hospital LOS; complications; and cost. Bivariate analysis was performed to evaluate changes in the primary outcomes over time, using chi-square for dichotomous variables and simple linear regression for continuous variables. To evaluate for possible effects of greater numbers of neurosurgical patients in baseline period one, comparisons were performed with and without inclusion of these patients.

Observed to predicted (O:P) ratios were calculated by dividing the actual mortality by the APACHE III-predicted mortality and the actual LOS by the predicted LOS for each study period. Differences between O:P ratios across time periods were compared using chi-square testing. To evaluate for possible time-related changes, differences between the intervention period and baseline period two and between baseline periods one and two were compared using chi-square analysis. In addition, APACHE analytic software was used to compare study period outcomes with APACHE cohort hospital "norms." Multiple linear regression was performed to evaluate whether differences in continuous outcome variables (cost and LOS) across study periods persisted after adjusting for APACHE III-predicted mortality.

RESULTS

Patient Characteristics

A total of 225 of 253 patients from baseline period one, 202 of 218 from baseline period two, and 201 of 221 from the intervention period met entry criteria. Patients were excluded because of an ICU stay of <4 hrs (5%), discharge to another hospital (2%), age of <16 yrs (0.5%), and incomplete data (1%). Patient characteristics are shown in Table 1. Groups were similar except for a greater number of "neurology primary system failure" patients in baseline period one. Removal of these neurology patients did not alter average age, ratio of male/female patients, racial distribution, average APACHE III score, or prevalence of chronic health items.

Clinical Outcomes

Mortality. Mortality data are shown in Table 2 and Figure 1. ICU mortality for

Table 1. Demographics

	Baseline 1	Baseline 2	Intervention	Chi-Square
Patients (no.)	225	202	201	.28
Age	62 (16–100)	60 (16–91)	61 (16–92)	
Gender (M%:F%)	55:45	63:37	57:43	.27
Race (%)				
White	80	85	77	.33
Black	18	14	22	
Other	<1	<1	<1	
Primary system failure (%)				
Cardiovascular	23	21	20	.83
Respiratory	3	9[a]	9[a]	.04
Neurology	22	4[a]	2[a]	.000
Gastrointestinal	20	34[a]	31[a]	.01
Genitourinary	10	6	15	.07
Metabolic/endocrine	1	2	2	.76
Hematologic	0	1	1	.60
Musculoskeletal	4	7	9	.27
Trauma	14	16	12	.64
Transplant	2	0	0	.07
Admit source (%)				
Operating/recovery room	75	76	83	
ER/other ICU/other hospital	22	21	14	.27
Floor/stepdown	4	3	3	
APACHE III score (median)	43.3	38.5	38.4	
Chronic health items (%)				
Leukemia	1	1	1	.64
Solid tumor with metastases	5	6	7	.89
Immunosuppression	4	0[a]	1[a]	.02
Hepatic failure	0	0	0	.51
Cirrhosis	1	0	3	.13
Diabetes mellitus	11.1%	6.9	16.4[b]	.05
Dialysis at admission	4	2	3	.71

M, male; F, female; ER, emergency room; ICU, intensive care unit; APACHE, Acute Physiology and Chronic Health Evaluation.

[a] $p < .05$ compared with baseline 1; [b] $p < .05$ compared with baseline 2. Demographic data on patients from each study period. Age values are mean with ranges in parentheses. APACHE III scores confidence intervals shown in parentheses. p Values are shown in the chi-square column.

Table 2. Mortality

	Baseline 1	Baseline 2	Intervention
ICU observed (%)	9.78	3.47[a]	1.49[a,b]
ICU APACHE predicted	5.6 (3.6–7.2)	2.82 (1.7–3.4)[a]	2.69 (1.5–3.5)[a]
ICU APACHE O:P	1.75	1.23[a]	0.56[a,b]
Hospital observed (%)	11.56	6.93[a]	4.48[a,b]
Hospital APACHE predicted	10.82 (8.1–13.0)	6.82 (5.2–8.2)[a]	6.28 (4.6–7.6)[a]
Hospital APACHE O:P	1.07	1.02	0.71[a,b]

		Intervention	
	Base 1–Base 2	Base 1	Base 2
Change in ICU O:P	−0.52 (−0.58, −0.46)	−1.19 (−1.25, −1.13)	−0.67 (−0.72, −0.63)
Change in hospital O:P	−0.06 (−0.13, −0.02)	−0.36 (−0.43, −0.28)	−0.30 (−0.37, −0.23)

ICU, intensive care unit; APACHE, Acute Physiology and Chronic Health Evaluation.

[a] $p < .05$ compared with baseline 1; [b] $p < .05$ compared with baseline 2; predicted mortality data are displayed as mean, with confidence interval in parenthesis.

Top panel: Observed mortality rate, APACHE-predicted mortality rate, and APACHE observed: predicted (O:P) ratios for ICU and hospital mortality during the three study periods.

Lower panel: Differences between APACHE O:P ratios for the study periods (with confidence intervals in parentheses). For ICU mortality, confidence intervals do not cross zero, demonstrating statistical difference between all time points. None of the confidence intervals cross each other, indicating that the change in mortality from baseline period 2 to the intervention period was greater than the change from baseline 1 to baseline 2.

the three periods was 9.8%, 3.5% and 1.5%, compared with APACHE III-predicted mortality of 5.6%, 2.8%, and 2.7%, respectively. Comparison of the O:P ratios demonstrates significant differences within and between time periods, with lower mortality during the intervention period (32% and 58% of baseline one and two, respectively). ICU mortality (O:P) during baseline period two was lower than during baseline period one; however, the magnitude of this difference was less than the difference between the intervention period and baseline period two. Observed/predicted hospital mortality was similar during both baseline periods and lower during the intervention period. ICU mortality rates (O:P) during baseline period one were similar with and without neurology patients (1.75 vs. 1.85). Stratification of patients into surgical (admitted from the operating room) and medical (admitted from the medical floor or emergency department) diagnoses groups (APACHE III classification) demonstrated ICU O:P mortality rates of 1.68 and 1.80 in baseline one, 1.32 and 0.77 in baseline two, and 0.68 and 0.0 in the intervention period, respectively.

Complications. The incidence of ICU complications during each study period is shown in Table 3. The overall complication rate for baseline period one, baseline period two, and the intervention period was 15.1%, 18.8%, and 9.5%, respectively.

Economic Outcomes

LOS. LOS data are shown in Table 4. ICU LOS was shorter during the intervention period (by 26% and 35%). Observed/predicted ICU LOS for the intervention period was 26% lower than in the APACHE database ($p < .01$), whereas the baseline period LOS did not differ from predicted. ICU LOS was greater in patients with complications (6.18 ± 10.4 [SD] vs. 1.88 ± 2.08 days). Patients staying 6 or more days in the ICU accounted for 50% and 40% of total ICU days during baseline periods one and two vs. 24% of days during the intervention period (Fig. 2). There were no differences in hospital LOS between groups. ICU LOS was similar with and without inclusion of neurology diagnosis group patients in baseline period one (3.66 vs. 3.50 APACHE days).

Costs. ICU costs were reduced by 25% and 31% in the intervention period compared with baseline one and two, respectively (Table 5). Analysis of individual cost elements during the ICU portion of the hospital stay demonstrated lower routine, radiology, and therapy costs (Table 6). Total hospital costs were 12% and 19% lower, respectively, for the intervention vs. baseline periods one and two, but these were not significant ($p = .15$ and $p = .10$). ICU-based costs, as a percentage of total hospital costs, were less during the intervention period (62% for baselines one and two and 53% for the intervention; $p = .0001$).

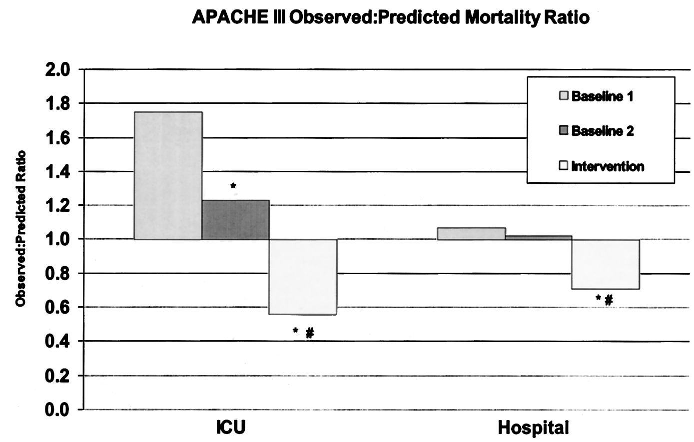

Figure 1. Acute Physiology and Chronic Health Evaluation III observed/predicted mortality ratio. *ICU,* intensive care unit. *$p < .05$ vs. baseline 1; #$p < .05$ vs. baseline 2.

Table 3. Complications

Complication	Baseline 1 No. (%)	Baseline 2 No. (%)	Intervention No. (%)
Sepsis	14	17	10
Reintubation	8	9	6
Myocardial infarction	3	4	1
Acute renal failure	4	6	4
Respiratory failure	1	3	2
GI bleed	4	10	2
Cardiac arrest	8	6	3
Readmission to ICU (within 48 hrs)	8	10	6
Total complications	50	65	34[a]
Total no. of patients with complications (%)	34 (15.1)	38 (18.8)	19 (9.5)[a]

GI, gastrointestinal; ICU, intensive care unit.

[a]$p < .05$ compared with baseline period 2. Incidence of ICU complications during the three study periods.

Table 4. Length of stay

	Baseline 1	Baseline 2	Intervention
ICU observed	2.71 (2.14–3.03)	3.06 (1.95–3.89)	2.0 (1.66–2.31)[a]
ICU APACHE observed	3.66	4.01	3.04
ICU APACHE predicted	3.82 (3.58–4.02)	3.63 (3.38–3.95)	3.54 (3.31–3.74)
ICU APACHE O:P	0.96	1.1	0.86[a]
Hospital observed	9.18 (8.04–10.44)	10.11 (8.32–11.94)	9.28 (7.87–10.82)
Hospital APACHE observed	10.16	10.64	9.9
Hospital APACHE predicted	16.04 (15.74–17.2)	16.44 (15.72–17.08)	16.28 (15.62–16.90)
Hospital APACHE O:P	0.63[a]	0.65[a]	0.61[a]

ICU, intensive care unit; APACHE, Acute Physiology and Chronic Health Evaluation; O:P, observed: predicted.

[a]$p < .01$ vs. baseline periods 1 and 2; [b]$p < .01$ vs. APACHE predicted. Observed values are actual days (total hours/24 hrs) from hospital census data; APACHE observed values are actual days calculated using standard APACHE methodology, which counts a day for each calendar day spent in the ICU. APACHE O:P ratios were calculated by dividing APACHE observed by APACHE predicted. Values are presented as means, with confidence intervals.

Regardless of the study period, hospital costs for patients with complications were three times those of patients without complications ($21,789 ± $33,292 [SD] vs. $7,218 ± $7,515). Sixty-four percent of the difference in cost between the baseline and intervention periods was associated with the higher incidence of complications in the baseline periods. When hospital costs were corrected for APACHE III score, predicted mortality quartile, and discharge status (survivor, nonsurvivor), these data remained unchanged.

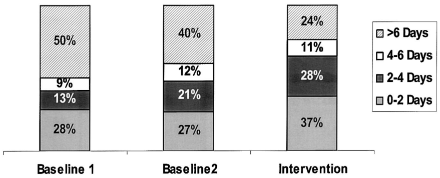

Figure 2. Patient's length of stay in the intensive care unit.

DISCUSSION

This study demonstrates a marked reduction in both observed and APACHE III-corrected ICU and hospital mortality when a remote management team provided continuous intensivist care. Shorter ICU length-of-stay and lower costs accompanied the improved clinical outcomes during this intervention. The efficacy of the intervention demonstrates that off-site intensivists can deliver effective ICU care and suggests that remote care models can improve clinical outcomes when continuous on-site intensivist coverage is not feasible.

ICU mortality during the intervention period was markedly lower than during the two baseline periods. Total hospital mortality was also lower during the intervention period. The decrease in overall hospital mortality indicates that mortality was not shifted from the ICU to the floor. In confirmation, the number of patients dying after ICU discharge was similar during all three periods. ICU mortality in the second baseline period was lower than in the first baseline period. Although this may indicate a gradual improvement in ICU care, overall hospital mortality, complications, and costs were similar in the two baseline periods. Moreover, the decrease in mortality from baseline period 2 to the intervention period significantly exceeded that predicted from the decrease observed between the two baseline periods. The patients comprising baseline period one differed from those in the two other study periods; severity of illness was higher, and there were more neurology patients. Although the latter difference appeared to have no effect on mortality, it is interesting to

Table 5. Cost data

	Baseline 1 ($)	Baseline 2 ($)	Intervention ($)	Intervention vs. Baseline 1	Intervention vs. Baseline 2
ICU-based					
Inpatient costs	7,965 ± 8,669	8,922 ± 19,936	6,273 ± 6,330	0.79 (.0255)	0.70 (.0777)
Professional fees	3,192 ± 2,228	3,317 ± 4,349	2,133 ± 1,746	0.67 (.0001)	0.64 (.0005)
Total costs	11,157 ± 10,168	12,239 ± 23,448	8,417 ± 7,554	0.75 (.0022)	0.69 (.0308)
Hospital-based					
Inpatient costs	13,692 ± 13,688	15,211 ± 25,294	12,690 ± 13,023	0.93 (.4438)	0.83 (.2147)
Professional fees	4,457 ± 3,265	4,577 ± 5,129	3,244 ± 2,536	0.73 (.0001)	0.71 (.0012)
Total costs	18,149 ± 16,102	19,788 ± 29,809	15,935 ± 15,033	0.88 (.1513)	0.81 (.1077)

ICU, intensive care unit.

Values are mean dollars (entire ICU and hospital stay) ± SD. Comparisons between intervention and baseline periods show ratio of costs, with p values in parentheses.

Table 6. Inpatient cost data—shown by charge category

	Baseline 1 ($)	Baseline 2 ($)	Intervention ($)	Intervention vs. Baseline 1	Intervention vs. Baseline 2
ICU					
Routine	3,751 ± 4,306	3,809 ± 8,226	2,625 ± 2,587	0.72 (.0016)	0.69 (.0559)
Drug	545 ± 859	856 ± 3,382	415 ± 778	0.78 (.1105)	0.49 (.0768)
Radiology	610 ± 793	601 ± 1,079	374 ± 456	0.63 (.0003)	0.62 (.0072)
Lab	824 ± 1,026	981 ± 2,014	741 ± 1,055	0.92 (.4179)	0.75 (.1260)
Supplies	1,666 ± 2,018	1,723 ± 3,302	1,640 ± 1,948	1.01 (.8959)	0.95 (.7600)
Therapies	568 ± 1,270	698 ± 2,171	306 ± 695	0.55 (.0110)	0.44 (.0169)
Other	1,487 ± 2,771	1,353 ± 3,198	983 ± 2,072	0.68 (.0390)	0.73 (.1761)
Hospital					
Routine	6,765 ± 7,227	6,983 ± 10,970	5,853 ± 6,145	0.89 (.1712)	0.84 (.2104)
Drug	1,027 ± 1,531	1,412 ± 3,862	870 ± 1,208	0.87 (.2532)	0.62 (.0623)
Radiology	1,082 ± 1,157	1,107 ± 1,473	962 ± 1,143	0.91 (.2902)	0.87 (.2779)
Lab	1,457 ± 1,642	1,675 ± 2,769	1,450 ± 1,569	1.02 (.9962)	0.87 (.3231)
Supplies	2,225 ± 2,433	2,324 ± 4,141	2,204 ± 2,562	1.02 (.9349)	0.95 (.7318)
Therapies	1,134 ± 1,774	1,296 ± 2,794	996 ± 1,776	0.90 (.4249)	0.77 (.2048)
Other	1,966 ± 3,332	1,817 ± 3,870	1,399 ± 2,287	0.73 (.0471)	0.77 (.1950)

ICU, intensive care unit.

Values are mean dollars (1996) ± SD. Comparisons between intervention and baseline periods show the ratio of costs during intervention and baseline, with p values in parentheses.

The results suggest that telemedicine is an alternate means to provide high-quality, proactive patient management.

speculate whether performance is adversely affected by larger numbers of severely ill patients. None of the patients excluded from analysis during the study period because of failure to meet age, time in the ICU, or complete data requirements died; follow-up data are not available for patients discharged to other hospitals.

The reduction in mortality during the intervention period is likely the result of the lower incidence of complications, which are strongly associated with mortality (27). Recent evidence suggests that medical errors in hospitalized patients are common and cause thousands of deaths annually (4). Avoidable adverse events occur with greater frequency in ICU patients (5, 6) and, because of the prevalence of co-morbid conditions in this population, often result in significant morbidity and mortality. The reduced number of complications during the intervention period confirms that many adverse events in ICU patients can be prevented. Moreover, the magnitude of the improvement in clinical outcomes highlights that fundamental care program changes offer the greatest opportunity to achieve breakthrough results.

Data from multiple ICU environments (medical, surgical, pediatric) indicate that intensivist-based care programs reduce complications and deliver improved patient outcomes (7–15). The value of intensivist care models likely derives from multiple sources. Intensivists are familiar with the spectrum of problems encountered in critically ill patients, they coordinate the care plan, and they provide continuous, proactive care. Several countries have mandated around-the-clock on-site intensivist coverage in their ICUs (28). In the United States, however, only 50% of hospitals have intensivists available, and the most prevalent model has them providing limited consultative coverage (16). The greatest barrier to implementing continuous intensivist care is the limited number of practicing intensivists in the United States. Of the estimated 10,000 board-certified intensivists (29), only 6,000–7,000 actively practice critical care, and most do so on a part-time basis (16). As many as 30,000 full-time intensivists would be required to provide 24 hrs a day, 7 days a week on-site coverage for the 7,500 ICUs (non-critical care unit) in this country. The shortage of intensivists is expected to worsen during the next 10–20 yrs as the demand for intensive care services increases with the aging U.S. population (16, 18), highlighting the need for alternate effective care models.

The current study evaluated the feasibility of providing expert, continuous, proactive ICU care remotely. Although no attempt was made to compare remote intensivist care with equivalent on-site coverage, the marked improvement in clinical outcomes indicates that this methodology is efficacious. After completion of the study, during which time ICU care reverted back to the model in place before the intervention, the hospital decided to move to an on-site, high-intensity intensivist care model. No severity-adjusted outcome data are available from the post-study period.

Intensivist-based care models have been shown to reduce LOS and resource utilization (10, 13), and we noted a reduction in ICU LOS and costs with remote management. A lower incidence of complications likely contributed to the cost savings (27). A small subset of outliers (who had ICU stays of >6 days) accounted for a disproportionate amount of resource consumption. During the baseline periods, 45% of patient days were attributed to these outliers (8.2% of the population). During the intervention period, outliers declined to 4.5% of the population, accounting for 24% of patient days. Other potential contributors to shorter LOS include expedited patient management with continuous care (e.g., time/extubation) and a change in discharge patterns. The latter is unlikely because study intensivists had no direct influence over patient discharge. Hospital LOS did not change during the intervention period. This probably reflects the fact that the intervention did not involve physician floor care and that established practice patterns often dictate length-of-stay after operative procedures.

Our economic analysis included the cost of the telemedicine service. The net decrease in professional fees, despite the addition of this new service, likely is attributable to a reduction in total ICU days, fewer radiographs, and electrocardiograms and to a reduced need for subspecialty consultations. These numbers should not be expected to reflect the economics of providing similar services commercially. Physician costs were based on academic salaries rather than professional fees for services rendered (which are not currently reimbursed by most payors) and were computed using actual time spent participating in ICU care. System costs did not include software development or maintenance. Moreover, fundamental alterations in system architecture would be needed to enhance stability, simplify use, and enable scalability, making cost projections uncertain. Thus, although the intervention reduced costs, the economic implications of remote ICU care will not be known until self-sustaining commercial implementations are deployed and their impact evaluated.

The rationale for this study was to evaluate whether currently available technology could extend the effective reach of intensivists, thereby offering the potential to leverage the limited U.S. intensivist physician supply over a greater patient base. The results suggest that telemedicine is an alternate means to provide high-quality, proactive patient management. The potential implications of the study are far reaching. Most hospitals do not have continuous intensivist coverage; many have no intensivists at any time. The lack of high-intensity ICU physician care likely translates into thousands of unnecessary deaths and millions of wasted dollars. The present study suggests that remote care may offer an alternate means of addressing this problem. Additional studies are required to determine whether effectiveness is maintained when greater numbers of patients are managed, whether efficacy is similar in other types of ICUs, and what it costs to implement commercially viable remote care programs.

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APPENDIX

Criteria for Intensive Care Unit (ICU) Complications/Adverse Events

Myocardial infarction	New Q waves or ST segment changes >1 mm with CPK-MB >2× normal and CPK-MB% >4%
Cardiac arrest	Advanced Cardiac Life Support or cardiac or respiratory arrest
Reintubation	Reinsertion of an endotracheal tube after extubation
Pulmonary failure	Presence of dyspnea and chest radiographic findings compatible with infiltrates or edema and Pa_{O_2} of <70, despite an F_{IO_2} of >50% with and without an endotracheal tube in place
Acute renal failure	>2 times baseline creatinine and an increase of >2 mg/dL
GI bleed	Presence of GI hemorrhage, manifested as hematemesis, melena, hematochezia, or blood in NG tube, requiring transfusion of >1 unit of PRBC for two consecutive days
Readmission to ICU	Return to ICU within 48 hrs of ICU discharge
Sepsis	Recognized pathogen isolated from blood, sputum, or urine Three of the four following criteria related to the onset of sepsis: 1. Core temperature of >38° or <36° (rectal, central, or tympanic; add 1°C for oral) 2. Heart rate of >90 beats/min in the absence of heart block or β blockers 3. Respiratory rate of >20 breaths/min or minute ventilation of >10 L/min 4. White blood cell count of >12,000 mm^3 or <4,000/mm^3 or >10% bands and, arterial systolic pressure of <90 mm Hg for 1 hr, despite adequate filling pressures (pulmonary artery wedge, >12 mm Hg) or the administration of an intravenous fluid bolus (>500 mL over 1 hr), or a need for vasopressors to maintain systolic blood pressure at >90 mm Hg.

CPK-MB, creatine phosphokinase-myoglobin; GI, gastrointestinal; NG, nasogastric; PRBC, packed red blood cells.