Effect of a multiple-site intensive care unit telemedicine program on clinical and economic outcomes: An alternative paradigm for intensivist staffing*

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Objective: **To examine whether a supplemental remote intensive care unit (ICU) care program, implemented by an integrated delivery network using a commercial telemedicine and information technology system, can improve clinical and economic performance across multiple ICUs.**

Design: **Before-and-after trial to assess the effect of adding the supplemental remote ICU telemedicine program.**

Setting: **Two adult ICUs of a large tertiary care hospital.**

Patients: **A total of 2,140 patients receiving ICU care between 1999 and 2001.**

Interventions: **The remote care program used intensivists and physician extenders to provide supplemental monitoring and management of ICU patients for 19 hrs/day (noon to 7 am) from a centralized, off-site facility (eICU). Supporting software, including electronic data display, physician note- and order-writing applications, and a computer-based decision-support tool, were available both in the ICU and at the remote site. Clinical and economic performance during 6 months of the remote intensivist program was compared with performance before the intervention.**

Measurements and Main Results: **Hospital mortality for ICU patients was lower during the period of remote ICU care (9.4% vs. 12.9%; relative risk, 0.73; 95% confidence interval [CI], 0.55–0.95), and ICU length of stay was shorter (3.63 days [95% CI, 3.21–4.04] vs. 4.35 days [95% CI, 3.93–4.78]). Lower variable costs per case and higher hospital revenues (from increased case volumes) generated financial benefits in excess of program costs.**

Conclusions: **The addition of a supplemental, telemedicine-based, remote intensivist program was associated with improved clinical outcomes and hospital financial performance. The magnitude of the improvements was similar to those reported in studies examining the impact of implementing on-site dedicated intensivist staffing models; however, factors other than the introduction of off-site intensivist staffing may have contributed to the observed results, including the introduction of computer-based tools and the increased focus on ICU performance. Although further studies are needed, the apparent success of this on-going multiple-site program, implemented with commercially available equipment, suggests that telemedicine may provide a means for hospitals to achieve quality improvements associated with intensivist care using fewer intensivists. (Crit Care Med 2004; 32:31–38)**

Key Words: telemedicine; remote consultation; critical care; intensivists; medical economics; e–health care

There has been considerable recent interest in intensive care unit (ICU) performance, stimulated by several publications demonstrating superior clinical outcomes with a dedicated intensivist staffing model (1–4). Based on the strength of these data, the National Quality Forum (5), the Agency for Healthcare Research and Quality (6), and the Leapfrog Group (7), an advisory board developing healthcare purchasing standards for Fortune 500 companies, identified ICU physician staffing as an opportunity to reduce in-hospital mortality. Leapfrog Group estimated that 53,000 lives could be saved annually in the United States if this standard were implemented (8). Despite the superiority of the dedicated intensivist staffing model, only 10–15% of U.S. hospitals have such a program in place (9). A shortage of intensivists represents the major obstacle to widespread adoption of this care model (10). Moreover, demographic and manpower data suggest that the shortage of intensivists will worsen in the coming years (9).

Telemedicine has been proposed as a possible alternative means of bringing intensivist expertise to hospitals lacking sufficient numbers of these subspecialists (11, 12). As part of a research protocol, Rosenfeld et al. (12) reported that a 16-wk remote intensivist monitoring program reduced severity-adjusted hospital mortality for patients in a ten-bed surgical ICU by 30%, while simultaneously decreasing ICU length of stay (LOS) and costs. However, if telemedical ICU care is to be viewed as a solution to the intensivist shortage, it must be available outside of a research setting. Moreover, the previous study cared for patients in one ICU and did not evaluate whether telemedicine can allow intensivists to care for patients in multiple ICUs, a prerequisite if this technology is to extend the value of intensivists. The current study was undertaken to address these important issues by examining the clinical and economic impact of an ICU telemedicine program that was implemented with

***See also pp. 287 and 288.**

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commercially available equipment and provided care to patients in multiple ICUs.

MATERIALS AND METHODS

Setting. The ICU telemedicine program was initiated in three ICUs in two affiliated hospitals of Sentara Healthcare, an integrated delivery network. This study examines the clinical and economic effect of the program in two ICUs of one of the integrated delivery network hospitals. Program impact could not be quantified in the second hospital because only 15 of 22 ICU beds were networked, and nurses in that ICU selectively directed patients to the monitored beds (see "DISCUSSION" for further details). The study hospital is a 650-bed tertiary care teaching hospital. The program was implemented in a ten-bed general ICU that primarily cares for high-acuity medical patients (MICU) and an eight-bed surgical ICU that primarily cares for vascular surgery patients (SICU). The study was approved by the Sentara Healthcare institutional review board.

On-Site ICU Physician Staffing. The hospital has both medical and surgical house staff that participate in the care of patients on the teaching services (approximately 40% of ICU patients). The medical teaching service has an intensivist as the primary attending for all teaching service ICU patients in the MICU. For nonteaching service medical patients and for surgical patients, intensivists see patients in consultation at the discretion of the admitting physician (approximately 80% and 35% of patients for MICU and SICU, respectively). Consulting intensivists are primarily pulmonary subspecialists with critical care specialty certification. There was no mandatory intensivist involvement in ICU patient care for nonteaching service patients before the telemedical program, and other than the remote management program, this was unchanged during the study period. There were no changes in nurse staffing, clinical protocols, formalized physician care patterns, or technology systems (other than those used for the remote ICU equipment) during the study period.

Program Description. The remote ICU care program supplemented existing on-site care activities, which did not change as a result of the program. A commercial ICU telemedicine firm (VISICU, Baltimore, MD) installed all required hardware and software and trained local caregivers in the use of the system. The supplemental remote intensivist program operated from a dedicated facility (the eICU) that was off campus in a commercial office building in geographic proximity to the two hospitals. All patients in both the MICU and SICU were monitored from noon until 7 am (19 hrs/day) by the eICU staff, which included a board-certified intensivist, a critical care nurse, and a clerical person. These hours of supplemental care were selected because intensivists are generally present in the study ICUs from 7 am to noon. Intensivists were members of the integrated delivery network medical group, faculty of the medical school, or local practitioners; VISICU intensivists also participated to fill coverage gaps until new physicians could be recruited. All program intensivists were board certified in critical care and were credentialed at each participating hospital. Policies and procedures, developed by the hospital, with input from the telemedicine provider, defined eICU operating procedures, including shift durations, roles and responsibilities of the remote and on-site caregivers, and backup procedures. The hospital admitting physician continued to be the attending of record and was responsible for establishing the care plan and determining which on-site consultants should assist with care delivery. The attending physician also determined the level of intervention of the eICU team, ranging from retaining all decision-making authority (except in emergency situations—category 1) to delegating some or all off-hours decision-making authority to the remote intensivist team (categories 2–4). Initially, the majority of admitting physicians were category 1 or 2, but by the end of the run-in period, most were category 3 or 4. Regardless of physician category, the eICU intensivist reviewed all patient data at regular intervals, making virtual rounds based on the acuity of the patient (hourly for the sickest patients and at least once every 4 hrs for the most stable patients). The eICU staff served as the primary contact for the on-site nurses and were responsible for contacting physicians, responding to all emergencies, and initiating interventions (where authorized). Off-hours procedures were performed either by on-site personnel (including house staff), by physician assistants employed by the intensivist group, or by a physician who returned to the hospital. The on-site code team continued to respond to all cardiac and respiratory arrests. However, the remote intensivists were often the first to notice the problem or respond to the problem. The remote intensivist assisted in the conduct of all codes. Quality review was performed by the quality assurance committee of the hospital. An oversight committee met monthly to review program performance, facilitate effective communication, ensure rapid identification of any problems, and refine operations.

Technology Description. The commercial telemedicine vendor provided all technology components. A local-area network was installed in each ICU. This local-area network supported high-resolution, three-chip, pan-tilt, and zoom cameras, speakers, and microphones in each patient room. Bedside monitor data were captured directly from the central monitoring station in real time and stored in a relational database. This database also contained detailed patient information, including medications, lab results, active diagnoses, and therapies. These data were displayed on proprietary, ICU-specific information screens that could be accessed from the eICU and from desktop computers at the ICU nurses' station. Additional software included a computerized decision-support tool and note-writing and order-entry applications. A high-resolution, medical-grade scanner in the ICU was used to transmit radiographic images when required for clinical decision making. Each eICU caregiver monitored and managed care from a workstation composed of three desktop computers; one for video conferencing into each patient room and to the nurses' station, one for real-time bedside monitor viewing, and one to access clinical data, the decision-support software, and other applications. From this workstation, each caregiver was able to view patient data, communicate with on-site staff and patients, generate notes and orders, and access radiographic film files. A wide-area network, composed of redundant T-1 lines, was used to connect the eICU to each ICU. All data were encrypted before transmission across the wide-area network. Access to computer terminals was password protected, and electronic signatures were used to authenticate physicians' orders and notes. The wide-area network also enabled real-time viewing of bedside monitor data and dedicated phone connectivity. Figure 1 shows a schematic of the system configuration.

Study Design. The supplemental remote care program was initiated over a 3-month period from July through September of 2000. Individual units were brought up sequentially over this period, and operational refinements were made during the next 3 months (October through December). This study examines clinical and economic outcomes for ICU patients discharged from the hospital during the 6-month interval after the run-in period, from January 1 through June 30, 2001 (intervention period), and compares them with outcomes for patients discharged during the year before the project (July 1, 1999, through June 30, 2000—baseline period). Exclusion criteria include ICU admission of >30 days before the start of the study periods, hospital admission of >60 days before the start of the study periods, an ICU stay of <4 hrs, and transfer to an ICU that did not participate in the remote monitoring program within 12 hrs of admission to the ICU. For study patients with a stay in a nonprogram ICU during the same hospitalization as their MICU/SICU stay (<5% of total), days spent in the nonprogram ICU were included in ICU LOS analyses.

Clinical Outcome Measures. Major clinical outcome variables were ICU and hospital mortality and ICU and hospital LOS. Patients with an ICU LOS of ≥7 days were classified as outliers. The percentage of patients who were outliers and their average ICU LOS were secondary outcome measures.

Risk Adjustment. Acute Physiology and Chronic Health Evaluation III (APACHE III, Apache Medical Systems, McLean, VA) physiology scores were used to evaluate whether severity of illness changed between periods (13). APACHE physiology scores and predicted

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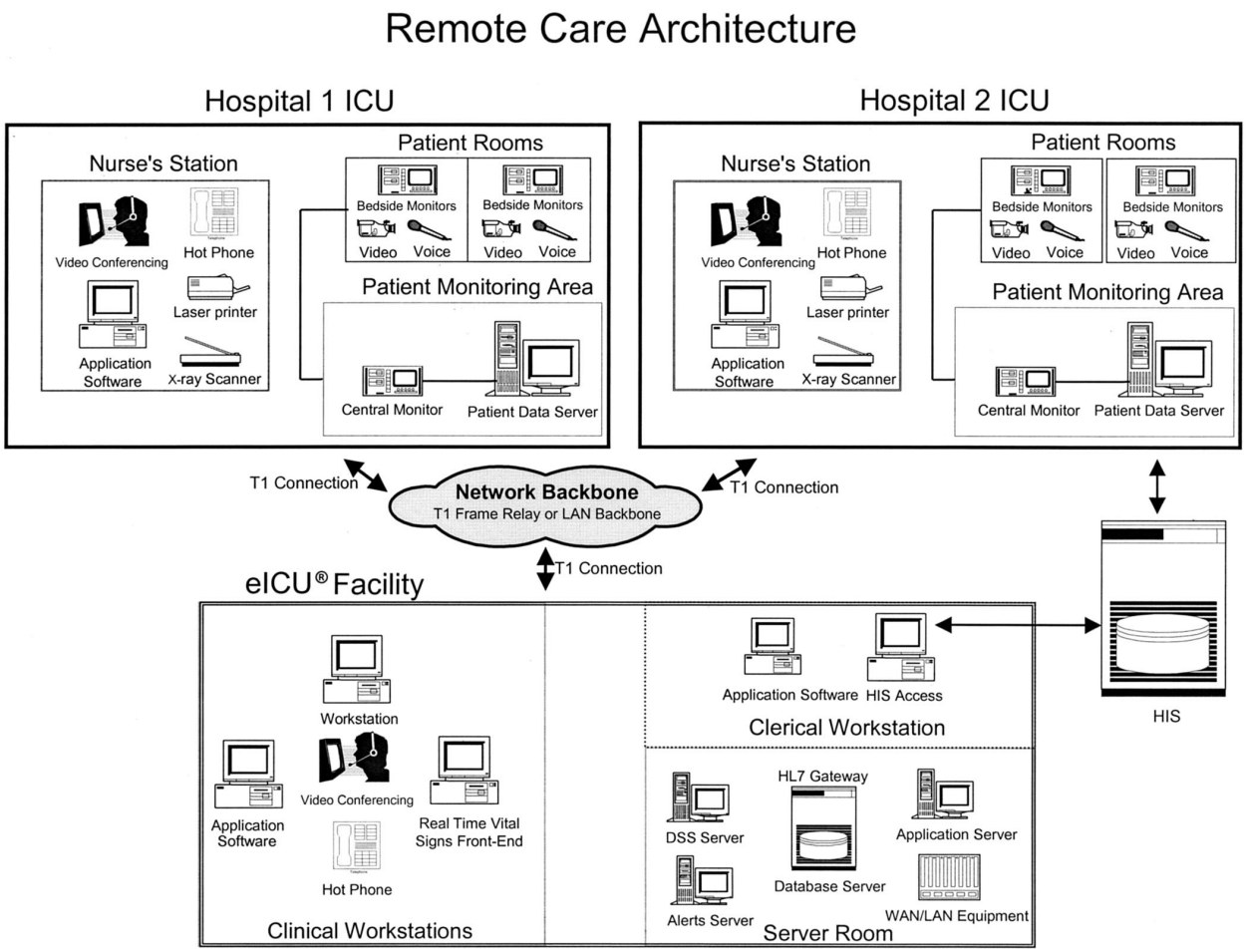

Figure 1. Schematic diagram showing the key technology components of the remote monitoring system. *T1 connection,* dedicated phone connection supporting data rates of 1.544 megabytes/sec; *eICU,* the centralized, off-site facility providing supplemental monitoring and management of intensive care unit patients; *HL7,* health level 7; *WAN,* wide-area network; *LAN,* local-area network; *DSS,* decision-support system; *HIS,* hospital information system.

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mortality and LOS were determined for all patients during the study period and on 50% of patients from the baseline period (approximately 300 patients per ICU). An outside group, not directly associated with the study, randomly selected patients for inclusion in the baseline chart abstraction; they did not have access to outcome information. Data abstraction was performed by Apache Medical Systems; the telemedicine provider paid for this work.

Financial Outcome Measures. A detailed financial analysis of the impact of the ICU telemedical program was performed by an independent consulting firm (Cap Gemini Ernst and Young, New York, NY) using detailed financial data provided by Sentara Healthcare. Average daily ICU and floor costs were determined for each ICU during the two study periods from individual patient charge data. The records of the patients used for the APACHE physiology score analysis were used for this analysis. All ICU and floor charges were allocated to the day the service was provided. Costs of care for each day of service were then calculated using individual departmental Medicare cost/charge ratios (14), with the variable component determined from national averages for departmental variable vs. fixed costs provided by Cap Gemini Ernst and Young. Average daily costs (MICU, SICU, and floor) for each period were used to determine per-case variable cost (product of average daily ICU/floor cost and average ICU and floor LOS). Costs for 1999 were converted to 2000 dollars using inflation data supplied by the hospital (4.5%). Hospital revenue data for patients admitted to study ICUs were collected to determine program impact on per-case revenue and to assess for any changes attributable to alterations in ICU case volume. Additional details of the Cap Gemini Ernst and Young financial analysis are available on request. Costs of the remote ICU care program were the hourly fees paid to the physicians for staffing the eICU and the monthly per-bed fees charged by the commercial telemedicine provider, which included charges for all hardware and software and eICU operating expenses. The monthly telemedicine costs included equipment purchase, installation, and ongoing software licensing and support. eICU physician staffing costs were calculated using two different methods: allocating all costs to the two study ICUs or allocating staffing costs over both hospitals monitored by the eICU, in proportion to the number of monitored beds in each facility.

Statistical Analysis. For all analyses, data from the two ICUs were examined in aggregate and individually. Descriptive statistics were used to evaluate demographic data, with chi-square analysis and Student's *t*-tests used to assess for differences between baseline and intervention periods. Changes in predicted mortality rates were evaluated using the APACHE III methodology (13). Because there were no differences in predicted outcomes, raw mortality data were analyzed using chi-square to evaluate for changes in mortality rates between study periods. Relative risk (RR) ratios and 95% confidence intervals (95% CI) were calculated using standard methodolo-

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gies. Changes in ICU and hospital LOS were evaluated using Wilcoxon's rank-sum test. The percentage of ICU LOS outliers and the outlier ICU LOS during the two periods were compared using chi-square and Wilcoxon's rank-sum tests, respectively. Physiology scores between study periods were compared using the Student's *t*-test.

RESULTS

A total of 2,140 patients were included in the analysis—1,396 in the baseline period and 744 in the intervention period. Four patients were excluded from the intervention group, one because of an ICU admission of >30 days before the study start date and three for ICU LOS of <4 hrs (one of whom died). Demographic data for the study patients are shown in Table 1. Although individual ICUs differed in patient composition, ICU demographics and patient acuity were similar in the two study periods.

Overall and individual ICU mortality and LOS data are shown in Tables 2 and 3. Mortality rate and LOS during the baseline period were higher in the MICU than in the SICU, and this difference persisted during the intervention period. Overall ICU and hospital mortality decreased by 26.7% (RR = 0.73, 95% CI = 0.53–1.02) and 26.4% (RR = 0.73, 95% CI = 0.55–0.95), respectively, during the intervention period (Fig. 2). ICU and hospital mortality during the intervention period decreased for the MICU (RR = 0.68, 95% CI = 0.46–0.98, and RR = 0.71, 95% CI = 0.52–0.95, respectively) but not for the SICU. Overall ICU LOS decreased during the intervention period (Wilcoxon's rank-sum test). Average ICU LOS decreased 16%, from 4.35 days (95% CI = 3.93–4.78) to 3.63 days (95% CI = 3.21–4.04); median LOS was unchanged (2 days). Overall hospital LOS was unchanged. ICU and hospital LOS decreased for SICU patients: average ICU LOS decreased by 24.5% and hospital LOS decreased by 19.8%. MICU average LOS decreased by 13.9%, but hospital LOS for the MICU patients was unchanged. Table 4 shows the percentage of LOS outliers in each ICU and the average ICU LOS of these patients during the two periods. The percentage of outliers decreased during the intervention period for the entire population by 16.8% (p = .07, RR = 0.83, 95% CI = 0.65–1.05) and for the SICU population by 37.2% (p = .0019, RR = 0.63, 95% CI = 0.40–0.99). Outlier ICU LOS was unchanged.

Financial data are shown in Tables 5 and 6. Variable costs per case decreased by $2,556 or 24.6%. The reduction in case cost was attributable to a decrease in LOS and to lower daily ICU ancillary costs (Table 5). Nursing labor (work hours per patient day) decreased slightly in the MICU from 19.1 to 17.9

Table 1. Patients' demographics

	All Patients		MICU		SICU	
	Base	Intervention	Base	Intervention	Base	Intervention
Patients, n	1396	744	631	359	765	385
Mean age, yrs (±SD)	61.3 (17.7)	60.1 (16.9)	58.8 (19.4)	56.9 (18.1)	63.3 (15.9)	62.9 (15.3)
Sex, M:F	782:614	370:374	314:317	172:187	468:297	198:187
Race, n						
White	696	360	244	142	452	218
Nonwhite	700	384	387	217	313	167
APS (±SD)	38.6 (23.5)	37.8 (22.8)	44.3 (26.5)	45.2 (25.1)	32.9 (18.6)	30.9 (17.9)

MICU, medical intensive care unit; SICU, surgical intensive care unit; M:F, male:female; APS, acute physiology score based on Acute Physiology and Chronic Health Evaluation III methodology.

Table 2. Mortality data

	All Patients		MICU		SICU	
	ICU	Hospital	ICU	Hospital	ICU	Hospital
Baseline (%)	120/1396 (8.6)	180/1396 (12.9)	88/631 (13.9)	125/631 (19.8)	32/765 (4.2)	55/765 (7.2)
Intervention (%)	47/744 (6.3)[a]	70/744 (9.4)[a]	34/359 (9.5)[a]	50/359 (13.9)[a]	13/385 (3.4)	21/385 (5.5)
Relative Risk (95% CI)	0.73 (0.53–1.02)	0.73 (0.55–0.95)	0.68 (0.46–0.98)	0.71 (0.52–0.95)	0.81 (0.43–1.55)	0.75 (0.46–1.23)

ICU, intensive care unit; MICU, medical intensive care unit; SICU, surgical intensive care unit; CI, confidence interval.
[a]$p < .05$ compared with base period.

Table 3. Length of stay (LOS) data

	All Patients		MICU		SICU	
	Base	Intervention	Base	Intervention	Base	Intervention
Mean ICU LOS, days (95% CI)	4.35 (3.93–4.78)	3.63[a] (3.21–4.04)	5.62 (4.88–6.35)	4.84[a] (4.16–5.51)	3.30 (2.83–3.78)	2.49[a] (2.02–2.97)
Mean hospital LOS, days (95% CI)	12.77 (11.89–13.65)	11.14 (10.26–12.03)	14.93 (13.4–16.45)	13.61 (12.11–15.17)	11.00 (10.01–11.98)	8.83[a] (7.89–9.76)

MICU, medical intensive care unit; SICU, surgical intensive care unit; ICU, intensive care unit; CI, confidence interval.
[a]$p < .05$ compared with base period (Wilcoxon's rank-sum test); LOS data are mean with confidence intervals shown in parentheses

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hrs and was unchanged in the SICU (20.6 vs. 20.1 hrs). Average per-patient hospital revenue was unchanged for the MICU population and increased by 16% for the SICU population. The number of ICU cases per month increased by 7% as a result of capacity created by the ICU LOS reduction. Figure 3 shows revenue, variable costs, and contribution margin (gross revenue minus variable costs) for the two ICUs during the baseline and intervention period. Monthly contribution margin increased by $524,000 (66%) during the intervention period, generating a financial benefit of $3.14 million over the 6-month intervention period. Program costs (hardware and software leasing, technical support, and eICU operating expenses, excluding physician reimbursement) for the 6-month period were $248,000 for the study ICUs. eICU physician staffing costs were $624,000; proportional allocation between the two hospitals served by the eICU (based on ICU beds) equates to an estimated physician cost of $341,000.

DISCUSSION

Results of the present study demonstrate improved clinical outcomes and financial performance coincident with the addition of a program of remote intensivist monitoring. Patient mortality rates for both the ICU stay and the hospitalization were lower when routine care was supplemented by remote intensivist management. Average ICU LOS during the supplemental care period was lower; there was no change in hospital LOS. Costs of care were reduced as a result of both a reduction in LOS and a decrease in daily costs of ICU care. In addition, the reduction in ICU LOS created new capacity that enabled additional patients to be cared for in the two ICUs.

Both a medical and surgical ICU were included in the study, with different disease processes and on-site care teams. There were small but important differences in the results observed in the two ICUs. The decrease in mortality rate in the SICU did not achieve statistical significance. This may reflect lower efficacy in this population and an insufficient sample size to show moderate mortality reductions, given the lower baseline mortality rate in this group [7.2% vs. 19.8% in the MICU]. ICU LOS decreased in both MICU and SICU. However, hospital LOS and the percentage of outliers decreased only in the SICU. We hypothesize that this is attributable to differences in ICU utilization. The majority of SICU patients are admitted electively after major sur-

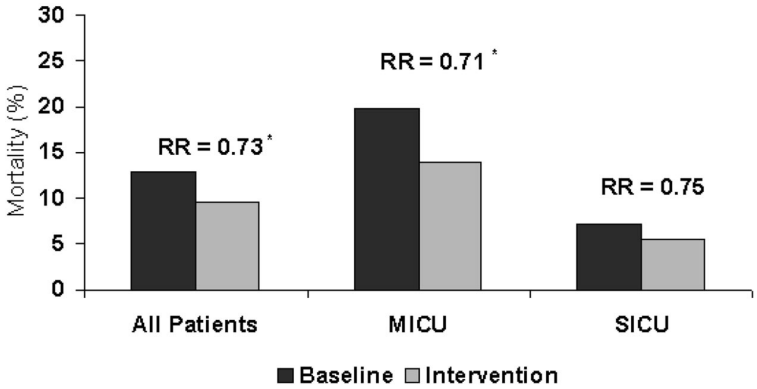

Figure 2. Hospital mortality data for all patients (medical intensive care unit [*MICU*] and surgical intensive care unit [*SICU*] patients) during the baseline period and the intervention period. *RR*, relative risk; *$p < .05$ compared with baseline period.

Table 4. Intensive care unit (ICU) outliers[a]

	All Patients		MICU		SICU	
	Base	Intervention	Base	Intervention	Base	Intervention
No. of outliers (%)	194/1396 (13.9)	86/744 (11.6)	122/631 (19.3)	63/359 (17.5)	72/765 (9.4)	23/385 (5.9)[b]
Median ICU LOS (25th–75th quartiles)	14.0 (10–25.8)	14.1 (9.4–21.0)	14.0 (10–19.5)	13.9 (9.3–19.5)	14.5 (10–25.3)	15.0 (10.3–23.7)

MICU, medical intensive care unit; SICU, surgical intensive care unit; LOS, length of stay.
[a]Outliers, patients with an ICU LOS of ≥7 days; [b]$p < .05$ compared with base period.

Table 5. Cost and revenue data

	All Patients		MICU		SICU	
	Base	Intervention	Base	Intervention	Base	Intervention
Average ICU daily cost	$1,648	$1,411	$1,303	$1,041	$1,933	$1,756
Average floor daily cost	$389	$366	$387	$394	$390	$340
Average case cost[a]	$10,444	$7,871	$10,926	$8,494	$9,698	$6,528
Average case revenue	$17,276	$18,510	$17,281	$16,950	$17,272	$19,964
Average case contribution margin	$6,832	$10,639	$6,355	$8,456	$7,574	$13,436
Cases per month	116.4[b]	124	52.6	59.8	63.8[b]	64.2
Contribution margin per month	$795,245	$1,319,236	$334,273	$505,669	$483,221	$862,591

MICU, medical intensive care unit; SICU, surgical intensive care unit; ICU, intensive care unit.
[a]Calculated from average daily ICU and floor costs and average ICU and floor lengths of stay; [b]SICU during the baseline period had ten beds.

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Table 6. Ancillary cost components[a]

	MICU		SICU	
	Base	Intervention	Base	Intervention
Laboratories	$109	$113	$142	$135
Pharmacy	$225	$188	$172	$157
Radiology	$41	$42	$35	$31
Supplies	$429	$295	$728	$624
Therapies (including respiratory)	$187	$68	$99	$52

MICU, medical intensive care unit; SICU, surgical intensive care unit.
[a]Cost figures are per-patient daily averages.

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gery because they are at risk for complications. We speculate that the supplemental remote intensivist management reduced the prevalence of avoidable complications. In contrast, MICU admission is usually the consequence of an established disease process. Improved care for these patients increases the likelihood of recovery (and may prevent secondary complications that can increase LOS) but cannot immediately return the patient to health.

Considerable effort was devoted to controlling for changes in patient mix and severity of illness between the two study periods. During the study period, ICU admission criteria were identical to those during the baseline period. Patients were admitted to study ICUs based on primary disease process, not physician preference. There were more women in the SICU in the intervention period, but this difference was not statistically significant. Physiologic acuity and predicted mortality and LOS at ICU admission were similar during the two periods. Despite the apparent similarity of the two populations, the use of historical controls always raises concerns about possible changes in patient mix. The shorter duration of the intervention period could have introduced differences related to seasonal variation in severity of illness; however, the inclusion of the winter months in the intervention period would be expected to bias the results in the opposite direction. For the baseline period, 50% of patient charts were abstracted and used for the severity of illness analysis. Individuals not associated with the clinical trial and blinded to clinical outcomes randomly selected patients for abstraction and performed the data abstraction. Although this sample should be representative of the entire population, there is always the possibility of sampling error. All patient records were abstracted during the program period.

A third ICU received supplemental remote ICU care during the study period. However, only 65% of the beds in this facility were monitored. The nurses in this facility assigned patients to the monitored beds based on patient acuity, intervention status (e.g., do-not-resuscitate order) and physician preference. Because factors other than disease severity were used to allocate the monitored beds (and these were not captured during the baseline period), we did not believe that outcomes for program patients could be compared with those during the baseline period. The lack of interpretable data from this third ICU represents a major weakness of the present study and prevents any conclusion about efficacy across all 36 beds.

Although it is interesting to speculate that the improved clinical outcomes during the intervention period were attributable to the addition of the remote intensivist-led management program, the actual basis for the observed changes is not known. Previous studies have demonstrated that converting from a multiple-consultant ICU care model to an on-site dedicated intensivist model during daytime hours results in improvements in major clinical outcomes of a similar magnitude to those observed in the present study (15, 16). Augmented physician presence, greater domain expertise, and integration of care responsibilities have been proposed to explain the benefits of the dedicated intensivist care model. The remote monitoring program markedly increased physician oversight and availability. Patients were monitored continuously from noon until 7 am of the following day. Another possible explanation for the improved outcomes was the introduction of the computer systems that allowed the eICU staff to view patient information, create physician notes, and access decision-support tools. These software tools were also made available to on-site caregivers so that key clinical data (e.g., physician notes) could be available to the eICU staff. Whether the introduction of this technology contributed to program efficacy is not known. Another possible factor was the increased institutional focus on ICU care that accompanied the introduction of this high-profile new clinical program. This attention may have altered on-site caregiver behavior. Although there were no organized changes in on-site care processes, subtle changes may have occurred. Additional studies are needed to both better understand the consequences of eICU actions (type of intervention, frequency, efficacy), the benefits of the supporting technology, the nature of changes in on-site care processes, and the sustainability of the results—including the potential liabilities associated with remote care (incomplete data, communication problems, working environment, and workload). These data will increase our understanding of this alternate care paradigm and potentially identify ways to improve on-site care as well.

Multiple different care models existed in the study ICUs during the baseline period, including multiple-consultant care and daytime care by a dedicated intensivist–led team. This mix of on-site physician care models persisted during the study period. Unfortunately, the number of patients included in the trial was insufficient to determine whether different on-site physician care models were associated with variations in clinical efficacy of the supplemental care program. Individual admitting physicians also varied in the autonomy they granted to the remote intensivist team, another potential variable affecting program efficacy. However, all patients were monitored continuously by the remote intensivist team, which likely facilitated problem recognition and shortened time to intervention. In addition, because the remote intensivist was the primary contact for the on-site nurses and was responsible for communicating with physicians, there was likely improved information transfer. Direct physician-to-physician communication also may have resulted in more diligent responses in those physicians electing for minimal direct eICU involvement.

Despite compelling data showing the superiority of dedicated intensivist care and pressure from payor groups to move to this model, 85–90% of U.S. hospitals do not have dedicated intensivists, even

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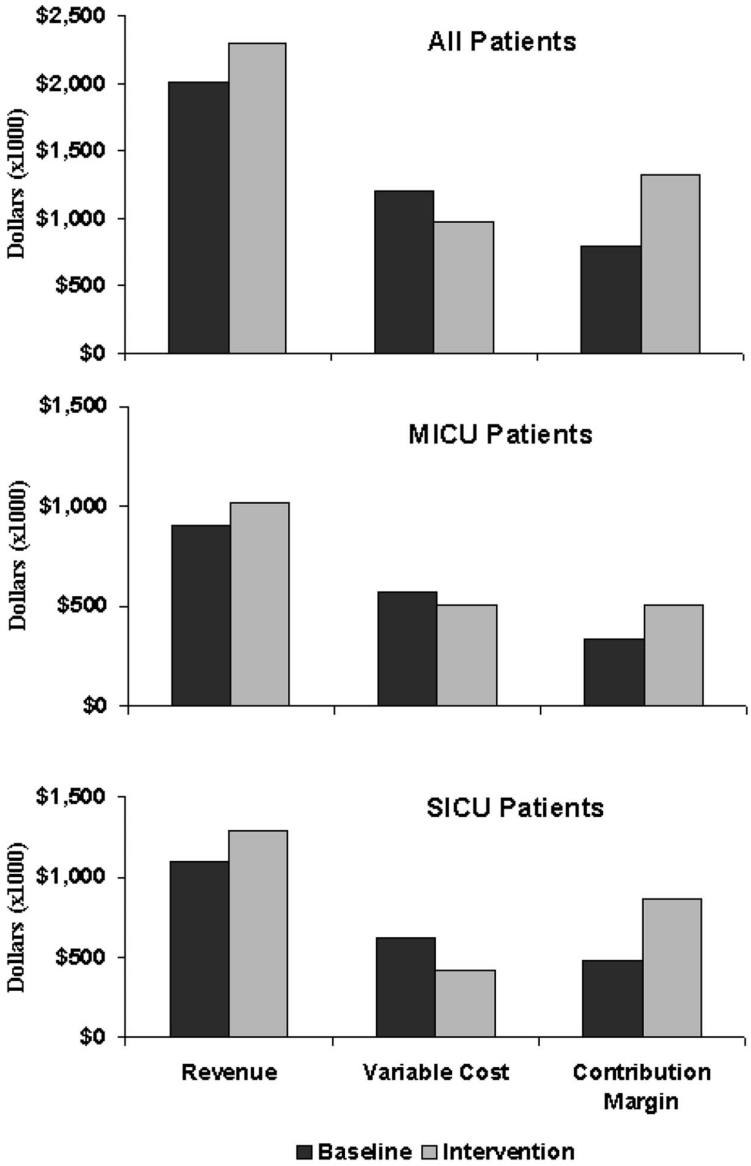

Figure 3. Average monthly revenue, variable costs, and contribution margin (revenue minus costs) for patients admitted to program intensive care units during the baseline period and the intervention period. *MICU,* medical intensive care unit; *SICU,* surgical intensive care unit.

during daytime hours (9). The major impediment cited by hospitals desiring to convert to this model is an inadequate supply of intensivists (10). A recent manpower study examining population demographics and specialty training choices suggests that this problem will worsen over the next decade (9). Intensivist access can be problematic, even in countries where dedicated intensivist staffing of ICUs is prevalent (e.g., United Kingdom). Many of these countries do not have enough ICU beds, and as a result, high-acuity patients often are cared for on general medical floors. Several recent studies cite improved outcomes when intensivists assist in the care of these patients (17, 18). However, ensuring appropriate oversight and management of high-acuity patients distributed throughout the hospital is challenging. The aging of the population in these countries will likely increase the number of high-acuity patients and create more demand for intensivist care (19, 20).

Rosenfeld et al. (12) suggested that telemedicine might provide a mechanism to improve clinical outcomes for ICU patients. These investigators examined the effect of a supplemental remote intensivist care program and observed significant reductions in mortality and ICU LOS and lower costs of care. Their trial did not, however, establish the feasibility of using remote intensivists to address ICU quality concerns created by the intensivist shortfall. Key unanswered questions included whether a remote intensivist program could be implemented outside of a research environment, whether a single intensivist-led team could supplement care in multiple sites simultaneously, and whether similar results could be achieved in different patient groups. The current study examines the clinical impact of a remote intensivist program that used commercially available equipment. Although the study hospital had to allocate time and resources to implement the program, all technical components were provided and installed by the commercial telemedicine vendor. The success of this installation suggests that other hospitals should be able to implement a similar program. Improvements in outcomes were observed in both a surgical and medical ICU, indicating potential efficacy in a wide variety of ICU patients. Finally, the remote intensivist-led team provided supplemental care to up to 33 patients simultaneously (18 in the two ICUs of the present study and 15 in the second hospital). This suggests that remote ICU care may be an effective means of extending intensivist management. However, several important questions remain. How many patients can a remote team effectively care for, and what is the optimal mix of caregivers? How should intensivists (and ICU nurses) divide their time between on-site and remote care? What is the skill set required for this new practice paradigm, and will training programs need to be modified? It is hoped, as other hospitals implement remote care programs, these questions will be answered.

Hospitals face considerable pressures to constrain costs and must evaluate critically the economic consequences of new clinical programs. ICU costs greatly exceed routine inpatient costs because of high staffing ratios and the use of expensive drugs, monitoring devices, and therapies (21, 22). Although ICU beds account for only 10% of total inpatient beds, the cost of caring for ICU patients can exceed 30% of total hospital costs (21, 22). Because of the high cost of ICU care, improved clinical outcomes can theoretically offset the costs of superior care

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The addition of a supplemental, telemedicine-based, remote intensivist program was associated with improved clinical outcomes and hospital financial performance.

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programs (e.g., dedicated intensivist care). Available data, although limited, suggest that costs of care may be lower with dedicated intensivists (23). The present study demonstrated cost savings from both LOS reduction and a decrease in daily costs. Cost savings were calculated based on individual departmental cost to charge ratios of the study hospital and national estimates of departmental variable cost ratios. This approach, although a widely accepted method for determining variable costs (14), may not reflect actual cost savings realized by the hospital. This is particularly an issue when patient volumes decrease because labor costs may not be controllable over short time intervals. However, the ICU census did not decrease when LOS decreased because additional patients were admitted to the ICU. We attribute the increase in ICU admissions to inadequate ICU bed availability during the baseline period. The two study ICUs had high occupancy rates before instituting the remote ICU care program, and the reduction in ICU LOS created additional ICU capacity. Many hospitals have similar problems with ICU capacity; oftentimes, the nonavailability of ICU beds causes emergency department diverts and adversely affects operating room procedures (24). Another factor that may have contributed to the backfill of ICU beds was the marketing activities of the hospital. Although not formally measured, families generally viewed the program as an enhancement in care; this may have attracted additional patients to the hospital. The additional cases cared for in the study ICUs during the supplemental intensivist program generated additional contribution margin for the hospital.

CONCLUSIONS

The current study demonstrates improved clinical and economic outcomes coincident with implementation of a program of remote ICU care in a tertiary care hospital. Assuming that the efficacy of this care model is confirmed in subsequent studies, supplementing on-site ICU care with a remote intensivist care program may represent an option for hospitals that desire to improve ICU clinical and financial performance. Because this model allows intensivists to care for patients in multiple locations simultaneously, it may help alleviate the current shortage of this subspecialty group.

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