CHEST

Original Research

CRITICAL CARE

The Costs of Critical Care Telemedicine Programs

A Systematic Review and Analysis

Gaurav Kumar, MD; Derik M. Falk, MD; Robert S. Bonello, MD; Jeremy M. Kahn, MD; Eli Perencevich, MD; and Peter Cram, MD, MBA

Background: **Implementation of telemedicine programs in ICUs (tele-ICUs) may improve patient outcomes, but the costs of these programs are unknown. We performed a systematic literature review to summarize existing data on the costs of tele-ICUs and collected detailed data on the costs of implementing a tele-ICU in a network of Veterans Health Administration (VHA) hospitals.**
Methods: **We conducted a systematic review of studies published between January 1, 1990, and July 1, 2011, reporting costs of tele-ICUs. Studies were summarized, and key cost data were abstracted. We then obtained the costs of implementing a tele-ICU in a network of seven VHA hospitals and report these costs in light of the existing literature.**
Results: **Our systematic review identified eight studies reporting tele-ICU costs. These studies suggested combined implementation and first year of operation costs for a tele-ICU of $50,000 to $100,000 per monitored ICU-bed. Changes in patient care costs after tele-ICU implementation ranged from a $3,000 reduction to a $5,600 increase in hospital cost per patient. VHA data suggested a cost for implementation and first year of operation of $70,000 to $87,000 per ICU-bed, depending on the depreciation methods applied.**
Conclusions: **The cost of tele-ICU implementation is substantial, and the impact of these programs on hospital costs or profits is unclear. Until additional data become available, clinicians and administrators should carefully weigh the clinical and economic aspects of tele-ICUs when considering investing in this technology.** ***CHEST 2013; 143(1):19–29***

Abbreviations: CIS = Clinical Information System; EHR = electronic health record; tele-ICU = telemedicine program in the ICU; VA = Veterans Affairs; VHA = Veterans Health Administration

ICUs deliver focused care to critically ill patients; but despite advances in ICU care, mortality rates remain high and vary significantly.[1,2] There is an increased effort to improve patient outcomes by providing dedicated intensivist staffing in all ICUs and promoting adoption of evidence-based therapies.[3-8] Access to intensivists has been hampered by an array of factors, most notably the limited supply of intensivists, particularly for smaller hospitals and rural geographic regions.[9-11] To improve the quality of critical care and extend the reach of the current intensivist workforce, at least 40 health-care systems in the United States have implemented telemedicine programs in ICUs (tele-ICUs).[12-15]

Tele-ICUs typically combine real-time videoconferencing, telemetry, and electronic health records (EHRs). A tele-ICU allows physician and nurse intensivists located in a centralized monitoring center to monitor and care for patients in multiple distant ICUs.[16,17] Although the tele-ICU concept may be similar across facilities, the technology and associated treatment protocols (eg, ventilator protocols, sepsis management, best practice protocols) can vary significantly across

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sites and programs. Thus, it is not surprising that previous studies have reached conflicting conclusions regarding whether tele-ICUs improve patient outcomes.[15,18,19]

Although studies evaluating the impact of tele-ICUs on patient outcomes and ICU teamwork have become increasingly available, studies assessing the cost of a tele-ICU have been slow to emerge.[20,21] The costs of

these programs are nontrivial, because tele-ICUs are typically purchased by the hospital implementing the system, and third-party payers (eg, Medicare, Medicaid, private insurance) do not reimburse for the capital costs or staffing of tele-ICUs.[22]

With this background, our first objective was to systematically review the existing literature that describes the costs of tele-ICUs. Our second objective was to provide the costs of tele-ICU implementation in a seven-hospital network within the Veterans Health Administration (VHA).

Materials and Methods

Literature Search

With the assistance of a trained medical librarian, we performed a systematic literature review to identify studies reporting costs associated with tele-ICUs. We searched PubMed, CINAHL, Academic Search Elite, Business Source Complete, ERIC, MasterFILE Premier, Health Source Academic Edition, EMBASE, Web of Science, and ABI/Inform from January 1, 1990, through July 1, 2011, using a Boolean strategy (e-Appendix 1). We also reviewed abstracts from the 2006 to 2010 annual meetings of the American College of Chest Physicians, American Thoracic Society, American Telemedicine Association, Society of Critical Care Medicine, and the American Public Health Association.

Study Selection and Data Abstraction

We identified 845 publications and seven conference abstracts of potential interest (Fig 1). Each source was reviewed by one of the study authors (G. K.) to determine whether the study was potentially eligible and met the following inclusion criteria: (1) involved the implementation of a tele-ICU and (2) provided original cost data associated with a tele-ICU. Since there is no standard definition of tele-ICUs, we considered tele-ICU to be any form of technology that used telemedicine to facilitate communication between remotely located intensivists and distant providers or patients in an ICU. Studies were excluded if (1) the tele-ICU was used to triage patients prior to ICU admission or (2) the publication provided duplicate data.

Two study authors (G. K. and P. C.) reviewed 49 publications of potential interest in duplicate, and eight studies were ultimately determined to be eligible.[23-30] Because each study was missing one or more important data elements (e-Appendix 2), we contacted the authors of each study in an effort to obtain additional data; all but two of the authors responded, but none were able to provide additional data.

Data were abstracted independently by at least two authors (G. K., D. M. F., and P. C.) using a data extraction tool (e-Appendix 2). Data elements included issues of study design, ICU and hospital organization, and tele-ICU costs.

Systematic Review Data Synthesis

We stratified the studies using a hierarchy for rating the quality of quasi-experimental studies proposed by Harris et al.[31] The nomenclature system provides a grade based on the study design, which can be used to suggest a degree of risk to the internal validity of the study's results.[31,32]

We categorized costs reported by each study into either tele-ICU costs or hospital variable costs (Table 1) building on the method of Roberts et al.[33] We subdivided tele-ICU costs into technology, staffing, and real-estate costs (Fig 2, Table 1).

Hospital variable costs are defined as the costs of resources used in providing patient care and may fluctuate depending on resource consumption by a given patient. To determine if health-care systems generate a profit or loss, a contribution margin is calculated by subtracting the total patient care costs from the revenue generated.[33-35]

Because tele-ICU vendors take into account the number of monitored beds when pricing these programs, we calculated the tele-ICU costs on a per-ICU bed metric to standardize the data across studies and allow for comparison with the VHA data.

VHA Data

We obtained detailed cost data from VHA for the implementation of a new tele-ICU within a network of seven hospitals. The costs were allocated to the previously mentioned subcategories, calculated for the entire tele-ICU in aggregate, and calculated for each of the participating hospitals individually.

As technology is an important component of tele-ICU costs, it is important to briefly comment on the existing information technology available within VHA. The VHA already has an advanced EHR; however, this EHR does not have the capability of managing continuous critical care data in a Clinical Information System (CIS). To clarify, the EHR allows for documentation and note writing, order entry with decision support, test result data, and demographic administrative data. A CIS manages clinical data such as vital signs, ventilator settings, IV infusion rates, or laboratory data; may provide decision support; and may use clinical alert systems. A CIS does not necessarily include other elements of an EHR. Optimal tele-ICUs include both an EHR and a real-time critical care CIS. The VHA tele-ICU implementation did not require purchase of an EHR as the VHA already had an EHR; however, the tele-ICU implementation did require purchase of a CIS, and these costs are included in our analysis.

We used the projected first-year costs of operating and staffing the tele-ICU monitoring center because the system only became

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Affiliations: From the Division of Pulmonary, Critical Care, and Occupational Health (Drs Kumar and Falk) and the Division of General Internal Medicine (Drs Perencevich and Cram), Department of Internal Medicine, University of Iowa Carver College of Medicine; the Center for Comprehensive Access and Delivery Research and Evaluation (Drs Kumar, Perencevich, and Cram), Iowa City Veterans Affairs Medical Center, Iowa City, IA; the Minneapolis Veterans Affairs Medical Center (Dr Bonello), Minneapolis, MN; and the Program on Critical Care Health Policy and Management (Dr Kahn), Department of Critical Care Medicine, University of Pittsburgh, Pittsburgh, PA.
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Correspondence to: Gaurav Kumar, MD, Division of Pulmonary, Critical Care, and Occupational Health, University of Iowa, Carver College of Medicine, C33GH, 200 Hawkins Dr, Iowa City, IA 52242; e-mail: gaurav-kumar@uiowa.edu

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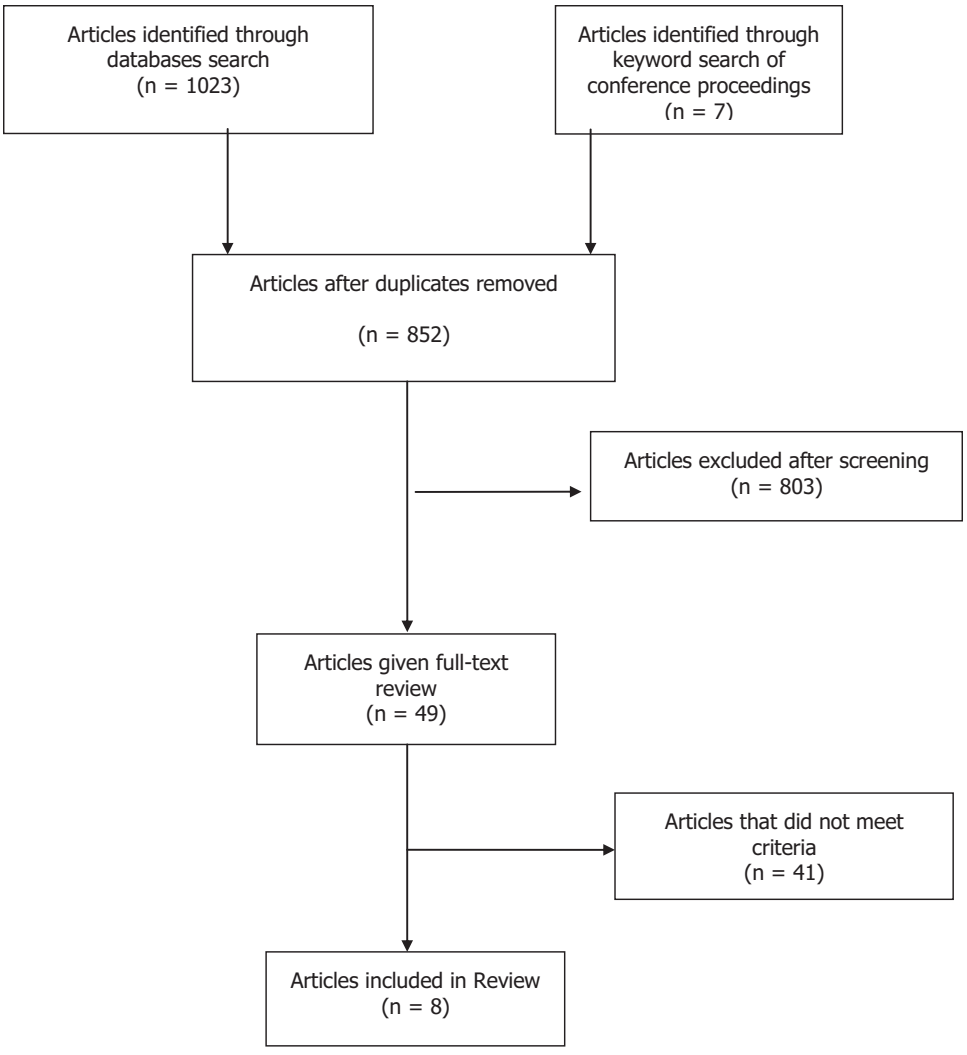

FIGURE 1. Telemedicine program in the ICU (tele-ICU) systematic review literature search flow diagram.

operational in August 2011, and, thus, the actual first-year operational costs are not yet complete. In an effort to provide perspective on how costs may vary when depreciation is factored into the tele-ICU, we applied three recognized depreciation methods. We reviewed Internal Revenue Service guidelines under the Modified Accelerated Cost Recovery System (MACRS) for medical technology and performed depreciation calculation by using both a straight line method and the 200% declining balance method for a total of 5 years of depreciation.[36] We applied both Internal Revenue Service methods, along with the sum-of-years' digits method, with 5-year depreciation and no remainder salvage value. This study was approved by the Iowa City Veterans Affairs (VA) Institutional Review Board.

RESULTS

Literature Review

Our literature review identified eight studies involving 29 ICUs from 26 hospitals that provided tele-ICU cost data (Table 2). All the studies used a quasi-experimental study design; all were of lower methodologic structure suggesting potential risks to internal validity.[31,32] Four studies had potential financial conflicts resulting from author ties to tele-ICU vendors.[23,25,27,28] Five studies implemented a commercial telemedicine system from a common vendor, but it was not reported if they concurrently implemented the vendor's CIS.[25,27-30] None of the studies reported the availability of an EHR. Seven studies involved community hospitals where intensivists were either not available or only served as a consultative role for the primary physician.[24-30] Finally, only five of the studies using real-time videoconferencing and monitoring equipment were monitoring patients 24 h/d.[23,25,28-30]

Tele-ICU Costs

There was significant variation in the cost data reported by the individual studies (Table 3). Three studies provided data on the technology, staffing, and real estate costs.[25,27,28] An unpublished report by the New England Healthcare Institute provided the most

Table 1—*Cost Categories for Tele-ICU*

Cost Category	Details
Telemedicine program	
Technology	Costs to purchase, install, and maintain
	Hardware: computers, bedside monitors, audio-visual equipment, upgraded systems
	Software and licenses: electronic health records, clinical information systems, tele-ICU software
	Equipment and networking: servers, scanner, Internet hubs and firewalls, phones, miscellaneous office equipment
	Technical support
	Communications: Internet service fees, telephony fees
Staffing	Costs pertaining to the central monitoring site staff: travel, training, salaries and benefits
	Staff: physician, critical care nurse or nurse practitioner, administrative, secretarial, janitorial, information technology support technician
Real estate	Real estate: rental property, space leasing, or facility owned property
	Cost: design, construction, or remodeling of space; architecture fees; contractor fees; furniture, utilities, property taxes, supplies, loss of used space, lease or rental agreement fee
Hospital variable	Hospital resources that can fluctuate depending on use for patient care.
	Nursing supplies (eg, IV tubing, wound care, IV access supplies)
	Pharmacy
	Laboratory
	Pathology
	Radiology and bedside diagnostics (eg, bedside ultrasound, radiographs, and imaging)
	Interventional services (eg, surgical procedures, interventional radiology procedures, cardiac procedures, interventional diagnostic testing)
	Ancillary services (eg, rehabilitation physical therapy, occupational therapy, dietician/kitchen, janitorial), miscellaneous supplies

Tele-ICU = telemedicine program in the ICU.

detail, reporting the costs of the technology, installation fees, staffing fees, monitoring site operating costs, and monitoring site maintenance costs.[28] Based on these studies, the estimated cost to implement the tele-ICU technology combined with the costs of monitoring of the site, operating the site, and staffing the tele-ICU for 1 year ranged from $50,000 to $100,000 per ICU-bed.

Six studies presented data concerning the impact of tele-ICUs on hospital variable costs (Table 3).[23-25,28-30] After tele-ICU implementation, studies with vendor affiliation reported a cost savings of $2,600 to $3,000 per patient and suggested that tele-ICUs increased hospital profits by $1,000 to $4,000 per patient.[23,25,28] Studies without vendor affiliation reported no variable cost savings and suggested increased hospital costs after implementation.[29,30] Despite the increase in hospital costs, one study suggested that the additional cost for tele-ICU could be compensated by a reduction in the hospital variable costs with improved patient outcomes when caring for a select patient population.[30] Of note, none of the studies indexed cost per bed or per patient, nor was there mention of using depreciation methods.

VHA Costs

In August 2011, the VHA activated a tele-ICU in a network of seven hospitals containing eight separate ICUs and 74 ICU beds. The monitoring site is located in a dedicated space within one of the hospitals that also contains two ICUs using the tele-ICU. The total cost for implementing the program and the estimated first-year operating costs of the monitoring site was $9,097,410; this translated into a cost of $123,000 per ICU-bed (Table 4). The total cost for technology ($5,196,661) included all hardware, software, equipment, networking, and licensing fees. The estimated cost for staffing and operating the monitoring site for the first year was $3,300,000 (27% of total costs); of note, staffing costs are incurred on a recurring basis. Also, there was a one-time technology vendor fee of $1,114,711 to provide ongoing maintenance, support, and licensing fees for a total of 5 years (not included in Table 4); this fee was added to the cost of technology when performing depreciation calculations. Depending on the chosen method of depreciation, the first-year costs for implementation and operation of the VHA tele-ICU were estimated at between $70,000 and $87,000 per ICU bed (Table 5).

Discussion

We conducted a systematic literature review of the costs of tele-ICUs and evaluated the costs of implementing a tele-ICU in a network of VHA hospitals. Although our literature review revealed many shortcomings in the published literature, our review suggests an initial cost of tele-ICU implementation and operation of $50,000 to $100,000 per ICU-bed in the first year. In analysis of detailed VHA data, we found the total cost for implementation combined with the total first-year tele-ICU operation costs to

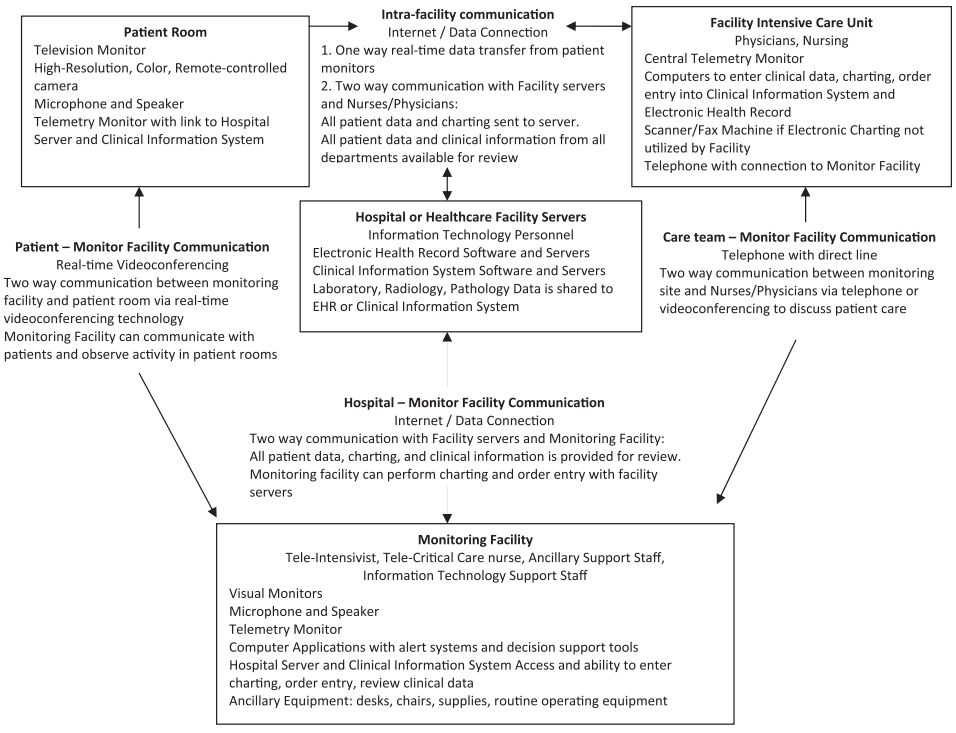

FIGURE 2. Tele-ICU: operational structure. Arrows represent communication pathways (with description of communication) between entities involved in the tele-ICU. Each box represents entities involved in the tele-ICUs (real estate). The technology and staffing required for each entity are described in the boxes. EHR = electronic health record. See Figure 1 legend for expansion of other abbreviation.

be $123,000 per ICU-bed. When initial investments are depreciated over 5 years, the combined costs for technology and operation in the first year are estimated at $70,000 to $87,000 per ICU-bed. Our results provide much-needed data regarding the resources required for implementation of a tele-ICU.

Several findings merit further comment. First, it is critical to mention the significant variation in how prior studies measured and reported costs. Several studies failed to include details of critical cost components for the tele-ICU.[23,24,26,29,30] For example, one-half of the studies did not provide the costs for implementation, technology, or staffing; and other studies failed to include a breakdown of the technology costs. None of the studies considered how tele-ICU coverage hours and interaction protocols might impact staffing costs for the monitoring centers or hospital profits. Although the technology is sold on a per-bed basis, few studies reported tele-ICU costs in a systematic way (eg, cost per patient or cost per bed). Smaller centers may initially consider a tele-ICU to be of high cost, but if a tele-ICU increases patient throughput and volume, a facility may realize a lower cost impact. With the availability of different technology options, interfacility comparisons may be difficult, as one facility may spend more than another to purchase technology. Likewise, few prior studies clearly specified the precise elements included in their cost analysis, including personnel costs, technology costs, and real estate costs. Authors, reviewers, and editors should work in concert to ensure that key cost elements are consistently reported to maximize the value of tele-ICU economic analyses.

Second, for tele-ICUs to be sustainable over the long term, hospital administrators will demand rigorous financial analyses of budgetary impact. Many of the prior studies purport cost savings based on improvements in surrogate outcomes (eg, ICU length of stay, ventilator-associated pneumonia prevention, ventilator days) but fail to provide actual cost data demonstrating true cost savings for tele-ICU.[37,38] Tele-ICUs have the potential to be economically viable if (1) they reduce costs or (2) they increase revenue.[33-35] Long-term viability of tele-ICUs will require more detailed data that these programs are cost effective.[39,40]

Third, our analysis of VHA data warrants discussion. We found that the costs of tele-ICU implementation combined with 1 year of operation was somewhat higher within VHA when compared with the detailed data obtained from a prior study.[28] However, after depreciation of initial investments was performed, costs within VHA appear similar to those provided in prior studies.[25,27] It is important to recognize that none of the prior studies mentioned use of deprecation

Table 2—*Characteristics of Studies*

Study/Year	Publication Type	Hierarchy	Discuss Limitation	Financial Interest With Vendor	Tele-ICU Vendor	Type of Hardware and Software Installed	EHR Used	No. of ICUs/Hospitals	Types of Institutions Involved?	Bedside Intensivist Staffing	Tele-ICU Operation Protocol[a]	Hours of Operation/Available
Rosenfeld et al[23]/2000	P	A3	No	Yes	Mixture of resources	Video monitor, computers, data software with direct telephone link. no CIS	No	1/1	Academic	Consult on-call	Reactive	24
Deodhar[24]/2002	P	A1	No	No	Mixture of resources	Computers, e-mail software, Internet. no CIS	No	1/1	Community	None	Consult	N/A
Breslow et al[25]/2004	P	A2	Yes	Yes	Philips VISICU	Audio/video monitor, telemetry, computers and networking	Yes	2/1	Community	Consult on-call	Proactive	24
Marcin et al[26]/2004	P	A1	Yes	No	…	…	…	2/2	Community	None	Reactive	24
Zawada et al[27]/2009	P	A2	No	Yes	Philips VISICU	Audio/video monitor, telemetry, computers and networking	…	4/11	Community	None	Proactive	20
Morrison et al[29]/2010	P	A2	Yes	No	Philips VISICU	Audio/video monitor, telemetry, computers and networking	…	4/2	Community	Consult on-call	Proactive and reactive	24
NEHI[28]/2010	O	A2	No	…	Philips VISICU	Audio/video monitor, telemetry, computers and networking	…	9/3	Mixed	Consult on-call	Proactive	24
Franzini et al[30]/2011	P	A2	Yes	No	Philips VISICU	Audio/video monitor, telemetry, computers and networking	…	6/5	Mixed	Consult on-call	Proactive and reactive	24

For details on the numbers in the Hierarchy column, see Harris et al.[31] A = conference or meeting abstract; CIS = Clinical Information System; EHR = electronic health record; … = information not provided or unknown; N/A = not applicable for this study, tele-ICU was a consultative email service between physicians. NEHI = New England Healthcare Institute; O = other; P = peer-review journal. See Table 1 legend for expansion of other abbreviation.

[a]Proactive = autonomy of the remote site to direct patient care if the bedside team was unavailable to respond to patient alerts or alarms; reactive = bedside team contacted the remote site for assistance.

Table 3—*Tele-ICU Systematic Review Costs*

Study/Year	Telemedicine Program Costs			Hospital Variable Costs	Cost Benefits	Comment
	Technology	Staffing	Real Estate			
Rosenfeld et al[23]/2000	…	…	…	Details provided	Reduced total ICU costs by $3,200 per patient Reduced hospital variable by $3,000 per patient	Study methods state intervention costs included, but not clearly provided or noted in the study Intervention costs not disclosed in discussion Changes in variable costs provided in Table 6 of study
Deodhar[24]/2002	e-Mail and computer: $300	…	No monitor facility	Provided	Cost savings of $75 per patient	e-Mail consultation only, no monitoring facility Savings are avoided transfers, interventions, consultations Did not include costs of physician time to respond to e-mail
Breslow et al[25]/2004	$496,000 annual	$624,000 annual physician staffing	…	Details provided	Reduced hospital variable cost by $2,600 per patient Generated additional hospital income of $4,000 per patient	Authors are vendor founders Limited intervention cost detail Change in variable costs provided in Table 6 of study No detail of how income was calculated
Marcin et al[26]/2004	…	…	…	…	Saved $200,000 per year in avoided transfers	No intervention cost data provided No variable cost data provided
Zawada et al[27]/2009	$1,490,000 one time	$2,195,200 annual	$1,267,000 annual	…	Saved $480,000 per year in avoided transfers	Limited intervention cost detail No data on changes in patient care costs or variable cost
Morrison et al[29]/2010	…	…	…	No detail provided	No cost savings noted No cost benefit analysis performed	Telemedicine program and all hospital costs (fixed and variable) were included in the total cost, but no breakdown provided
NEHI[28]/2010	$7,145,000 one time	$4,170,000 annual	$510,000 annual	No detail provided	Generated additional hospital income of $1,000-$4,000 per patient	Provided most detail of telemedicine program costs No details of hospital variable costs Implement and first year operation cost per bed: $101,940
Franzini et al[30]/2011	…	…	…	No detail provided	No cost savings noted Possible cost benefit in select population of patients	Intervention costs included in patient care costs, but no detail provided Study Tables 2 and 4: nonsignificant cost increase with noted mortality benefit for patients with SAPS score > 50

SAPS = Simplified Acute Physiology Score. See Table 1 and 2 legends for expansion of other abbreviations.

Table 4—*VHA Tele-ICU Costs*

Cost Category	Monitoring Facility (74 Beds)	Hospital 1, 2 ICUs (23 Beds)	Hospital 2 (10 Beds)	Hospital 3 (6 Beds)	Hospital 4 (16 Beds)	Hospital 5 (5 Beds)	Hospital 6 (5 Beds)	Hospital 7 (9 beds)	System Total (8 ICUs, 74 Beds)	% of Grand Total
Hardware/upgrades[a]	331,593.79	185,493.62	80,649.40	48,389.64	129,039.04	40,324.70	40,324.70	72,584.46	928,399.35	11
CIS software[b]	N/A	444,175.24	115,263.67	66,736.05	228,495.50	77,519.97	69,712.65	115,263.08	1,117,166.16	12
Telemedicine software[c]	414,000.00	167,533.60	73,982.00	47,889.20	113,121.20	41,366.00	41,366.00	67,458.80	966,716.80	10
Installation fees[d]	780,867.00	276,775.20	72,864.00	72,864.00	72,864.00	72,864.00	72,864.00	72,864.00	1,494,826.20	16
Equipment and network[e]	43,323.59	261,624.29	53,676.84	30,087.57	107,063.44	50,561.57	58,236.79	84,978.85	689,522.94	8
Technology total	1,569,784.38	1,335,601.95	396,435.91	265,996.46	650,583.18	282,636.24	282,504.14	413,149.19	5,196,661.45	57
Physician fees/y	1,576,800	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1,576,800	18
Nursing fees/y	1,295,987	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1,295,987	15
Technical fees/y	136,664	…	…	…	…	…	…	…	136,664	1
Managerial fees/y	384,744	…	…	…	…	…	…	…	384,744	5
Industry training	…	14,256.00	8,298.00	8,298.00	14,256.00	8,298.00	8,298.00	8,298.00	70,002.00	…
Nonindustry training	5,000	…	…	…	…	…	…	…	5,000	…
Travel expenditures	35,000	…	…	…	…	…	…	…	35,000	…
Staffing total	3,434,195	14,256.00	8,298.00	8,298.00	14,256.00	8,298.00	8,298.00	8,298.00	3,504,197.00	39
CIS site design prep	120,858.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	120,858.00	…
Tele-ICU site design prep	26,635.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	26,635.00	…
Monitoring facility construction	245,058.79	N/A	N/A	N/A	N/A	N/A	N/A	N/A	245,058.79	…
Operating supplies/y	4,000	N/A	N/A	N/A	N/A	N/A	N/A	N/A	4,000	…
Real estate total	396,551.79	N/A	N/A	N/A	N/A	N/A	N/A	N/A	396,551.79	4
Implementation and first y operation total	5,400,531.17	1,349,857.95	404,733.91	274,264.46	664,839.18	290,934.24	290,802.14	421,447.19	9,097,410.24	…
Implementation and first y operation total per ICU bed	72,980.15	58,689.48	40,473.39	45,710.74	41,552.45	58,186.85	58,160.43	46,827.47	122,937.98	…

Data are presented as dollars unless otherwise noted. N/A = not applicable as these components are only in the monitoring center; VHA = Veterans Health Administration. See Tables 1 and 2 legends for expansion of other abbreviations.

[a]Hardware/upgrades: all medical device hardware, monitoring hardware and upgrades to systems needed to implement the program.

[b]CIS software: cost for software, interfacing, and hardware fees for the CIS.

[c]Telemedicine software: cost for the software, interfacing, and hardware fees for the monitoring and telemetry system.

[d]Installation: fixed cost from the vendor for installation of the CIS and telemedicine.

[e]Equipment and network: specific costs for computers, monitors, desks, networking equipment including hubs and wiring, and installation for this equipment.

Table 5—*Technology Cost Depreciation Schedule*

Time	Straight-Line Method		Sum-of-Years' Digits Method		Declining Balance Method	
	Depreciation per y	Accumulated Depreciation	Depreciation per y	Accumulated Depreciation	Depreciation per y	Accumulated Depreciation
Y 1	1,262,274	1,262,274	2,103,791	2,103,791	2,524,549	2,524,549
Y 2	1,262,274	2,524,549	1,683,032	3,786,823	1,514,729	4,039,278
Y 3	1,262,274	3,786,823	1,262,274	5,049,097	908,838	4,948,115
Y 4	1,262,274	5,049,097	841,516	5,890,614	681,628	5,629,744
Y 5	1,262,274	6,311,372	420,758	6,311,372	681,628	6,311,372
Technology total for 5 y	6,311,372		6,311,372		6,311,372	
Estimated first y implementation and operation total per ICU bed	69,770.58		81,142.42		86,828.34	

Data are presented as dollars unless otherwise noted. Depreciation is performed on the capital costs for technology ($5,196,661) plus one-time fee for maintenance and support ($1,114,711); total of $6,311,372. The annual costs for operating the tele-ICU cannot be depreciated, and are not included in the depreciation schedule. The estimated first y cost total is the y 1 depreciated cost for technology plus all operating ($3,504,197) and real-estate costs ($396,552). See Table 1 legend for expansion of abbreviation.

methods. Moreover, the VHA already has an advanced EHR in all VA hospitals. Since the VHA did not purchase an EHR, the VA was not burdened with the complex technology integration issues that other hospitals with assorted computer systems may encounter. Finally, as a large integrated delivery system, the VHA tele-ICU implementation may have benefited from economies of scale that smaller health-care systems might not realize. Taking this into consideration, the costs of tele-ICU implementation within VHA could actually be lower than what would be expected in the private sector.

Our study has a number of limitations that merit mention. First, our systematic review was limited by the quality of the prior studies that have been conducted to date. Although the limitations were significant, our evaluation should provide a framework for future research. Second, our VHA data are limited to the initial implementation and estimated first-year monitoring site operation costs. Third, we could not calculate the cost effectiveness or cost savings of the tele-ICU, as such an analysis would require longer-term estimates of effectiveness (eg, reduction of ICU length of stay, reductions in imaging and laboratory testing, reduction in ICU complications) that are not yet available but will be a focus of our longer-term evaluation. Fourth, our study suggests that the cost effectiveness of a tele-ICU will vary between facilities and will depend on bed use and patient throughput (ie, case volume) and the number of beds over which the costs are depreciated (ie, economies of scale).

In conclusion, our review and analysis suggest an implementation and first-year operational cost of tele-ICUs of approximately $50,000 to $123,000 per monitored ICU-bed. The long-term economic impact of these programs remains unclear. In the meantime, clinicians and administrators should carefully weigh the clinical and economic aspects of tele-ICUs when considering investment in this technology.

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Dr Kumar: contributed to study concept and design; acquisition, analysis, and interpretation of data; and drafting and critical revision of the manuscript for important intellectual content.

Dr Falk: contributed to acquisition of data and drafting of the manuscript.

Dr Bonello: contributed to study concept and design, critical revision of the manuscript for important intellectual content, and administrative support.

Dr Kahn: contributed to study concept and design and critical revision of the manuscript for important intellectual content.

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Additional information: The e-Appendixes can be found in the "Supplemental Materials" area of the online article.

References

1. Berthelsen PG, Cronqvist M. The first intensive care unit in the world: Copenhagen 1953. *Acta Anaesthesiol Scand*. 2003;47(10):1190-1195.
2. Knaus WA, Wagner DP, Zimmerman JE, Draper EA. Variations in mortality and length of stay in intensive care units. *Ann Intern Med*. 1993;118(10):753-761.
3. Pronovost PJ, Rinke ML, Emery K, Dennison C, Blackledge C, Berenholtz SM. Interventions to reduce mortality among patients treated in intensive care units. *J Crit Care*. 2004; 19(3):158-164.
4. Thompson DR, Clemmer TP, Applefeld JJ, et al. Regionalization of critical care medicine: task force report of the American College of Critical Care Medicine. *Crit Care Med*. 1994;22(8):1306-1313.
5. Barnato AE, Kahn JM, Rubenfeld GD, et al. Prioritizing the organization and management of intensive care services in the United States: the PrOMIS Conference. *Crit Care Med*. 2007;35(4):1003-1011.
6. Pronovost PJ, Miller MR, Dorman T, Berenholtz SM, Rubin H. Developing and implementing measures of quality of care in the intensive care unit. *Curr Opin Crit Care*. 2001;7(4): 297-303.
7. Pronovost PJ, Angus DC, Dorman T, Robinson KA, Dremsizov TT, Young TL. Physician staffing patterns and clinical outcomes in critically ill patients: a systematic review. *JAMA*. 2002;288(17):2151-2162.
8. Young MP, Birkmeyer JD. Potential reduction in mortality rates using an intensivist model to manage intensive care units. *Eff Clin Pract*. 2000;3(6):284-289.
9. Angus DC, Kelley MA, Schmitz RJ, White A, Popovich JJ Jr; Committee on Manpower for Pulmonary and Critical Care Societies (COMPACCS). Caring for the critically ill patient. Current and projected workforce requirements for care of the critically ill and patients with pulmonary disease: can we meet the requirements of an aging population? *JAMA*. 2000; 284(21):2762-2770.
10. Ewart GW, Marcus L, Gaba MM, Bradner RH, Medina JL, Chandler EB. The critical care medicine crisis: a call for federal action: a white paper from the critical care professional societies. *Chest*. 2004;125(4):1518-1521.
11. Kelley MA, Angus D, Chalfin DB, et al. The critical care crisis in the United States: a report from the profession. *Chest*. 2004;125(4):1514-1517.
12. Nguyen YL, Kahn JM, Angus DC. Reorganizing adult critical care delivery: the role of regionalization, telemedicine, and community outreach. *Am J Respir Crit Care Med*. 2010; 181(11):1164-1169.
13. Cummings J, Krsek C, Vermoch K, Matuszewski K; University HealthSystem Consortium ICU Telemedicine Task Force. Intensive care unit telemedicine: review and consensus recommendations. *Am J Med Qual*. 2007;22(4):239-250.
14. Philips VISICU. eICU Program Factsheet. Baltimore, MD: Philips VISICU; 2010.
15. Lilly CM, Cody S, Zhao H, et al; University of Massachusetts Memorial Critical Care Operations Group. Hospital mortality, length of stay, and preventable complications among critically ill patients before and after tele-ICU reengineering of critical care processes. *JAMA*. 2011;305(21):2175-2183.
16. Grigsby J, Sanders JH. Telemedicine: where it is and where it's going. *Ann Intern Med*. 1998;129(2):123-127.
17. Grundy BL, Crawford P, Jones PK, et al. Telemedicine in critical care: an experiment in health care delivery. *JACEP*. 1977;6(10):439-444.
18. Young LB, Chan PS, Lu X, Nallamothu BK, Sasson C, Cram PM. Impact of telemedicine intensive care unit coverage on patient outcomes: a systematic review and meta-analysis. *Arch Intern Med*. 2011;171(6):498-506.
19. Thomas EJ, Lucke JF, Wueste L, Weavind L, Patel B. Association of telemedicine for remote monitoring of intensive care patients with mortality, complications, and length of stay. *JAMA*. 2009;302(24):2671-2678.
20. Talmor D, Shapiro N, Greenberg D, Stone PW, Neumann PJ. When is critical care medicine cost-effective? A systematic review of the cost-effectiveness literature. *Crit Care Med*. 2006;34(11):2738-2747.
21. Kahn JM, Hill NS, Lilly CM, et al. The research agenda in ICU telemedicine: a statement from the Critical Care Societies Collaborative. *Chest*. 2011;140(1):230-238.
22. Medicare Program; Payment Policies Under the Physician Fee Schedule and other revisions to Part B for CY 2012. *Fed Regist*. 2011;76(138):42772.
23. Rosenfeld BA, Dorman T, Breslow MJ, et al. Intensive care unit telemedicine: alternate paradigm for providing continuous intensivist care. *Crit Care Med*. 2000;28(12):3925-3931.
24. Deodhar J. Improving neonatal care at a primary health care facility in rural India with the help of Level III urban NICU using telemedicine. *Neonatal Intensive Care*. 2000;15(3): 21-22.
25. Breslow MJ, Rosenfeld BA, Doerfler M, et al. Effect of a multiple-site intensive care unit telemedicine program on clinical and economic outcomes: an alternative paradigm for intensivist staffing. *Crit Care Med*. 2004;32(1):31-38.
26. Marcin JP, Nesbitt TS, Struve S, Traugott C, Dimand R. Financial benefits of a pediatric intensive care unit-based telemedicine program to a rural adult intensive care unit: Impact of keeping acutely ill and injured children in their local community. *Telemed J E Health*. 2004;10(suppl 2): S1-S5.
27. Zawada ET Jr, Herr P, Larson D, Fromm R, Kapaska D, Erickson D. Impact of an intensive care unit telemedicine program on a rural health care system. *Postgrad Med*. 2009; 121(3):160-170.
28. New England Healthcare Institute. *Critical Care, Critical Choice: The Case for Tele-ICUs in Intensive Cares.* Cambridge, MA: Massachusetts Technology Collaborative and Health Technology Center; 2010.
29. Morrison JL, Cai Q, Davis N, et al. Clinical and economic outcomes of the electronic intensive care unit: results from two community hospitals. *Crit Care Med*. 2010;38(1):2-8.
30. Franzini L, Sail KR, Thomas EJ, Wueste L. Costs and cost-effectiveness of a telemedicine intensive care unit program in 6 intensive care units in a large health care system. *J Crit Care*. 2011;26(3):329.e1-6.
31. Harris AD, McGregor JC, Perencevich EN, et al. The use and interpretation of quasi-experimental studies in medical informatics. *J Am Med Inform Assoc*. 2006;13(1):16-23.
32. Shadish WR, Cook TD, Campbell DT. *Experimental and Quasi-Experimental Designs for Generalized Causal Inference*. Boston, MA: Houghton Mifflin; 2002.
33. Roberts RR, Frutos PW, Ciavarella GG, et al. Distribution of variable vs fixed costs of hospital care. *JAMA*. 1999;281(7): 644-649.
34. Kahn JM, Rubenfeld GD, Rohrbach J, Fuchs BD. Cost savings attributable to reductions in intensive care unit length of stay for mechanically ventilated patients. *Med Care*. 2008; 46(12):1226-1233.
35. Cleverley WO. Profitability analysis in the hospital industry. *Health Serv Res*. 1978;13(1):16-27.
36. U.S Department of the Treasury, Internal Revenue Service. *How To Depreciate Property. IRS Publication 946*. Washington, DC: US Government Printing Office; 2010.

37. Kohl B, Gutsche J, Kim P, Sites F, Ochroch E. Economic impact of EICU implementation in an academic surgical ICU [abstract]. *Crit Care Med*. 2007;35(suppl 12):A26.
38. Norman V, Kabani N, Mizell P, Stone D, Griebel J Jr, Tragico E. Effect of a telemedicine facilitated program on ICU length of stay (LOS) and financial performance [abstract]. *Crit Care Med*. 2009;37(suppl 12):A2.
39. Gold MR, Russell LB, Seigel JE, Weinstein MC. *Cost-Effectiveness in Health and Medicine*. New York, NY: Oxford University Press; 1996.
40. American Thoracic Society. Understanding costs and cost-effectiveness in critical care: report from the second American Thoracic Society workshop on outcomes research. *Am J Respir Crit Care Med*. 2002;165(4):540-550.