Published in final edited form as:

Crit Care Med. 2014 February ; 42(2): 362–368. doi:10.1097/CCM.0b013e3182a6419f.

Adoption of intensive care unit telemedicine in the United States

Jeremy M. Kahn, MD MS^{1,2}, Brandon D. Cicero, MPH¹, David J. Wallace, MD MPH^{1,3}, and Theodore J. Iwashyna, MD PhD^{4,5}

¹Clinical Research, Investigation and Systems Modeling of Acute Illness (CRISMA) Center; Department of Critical Care Medicine, University of Pittsburgh School of Medicine, Pittsburgh, PA, USA

²Department of Health Policy & Management; University of Pittsburgh Graduate School of Public Health, Pittsburgh PA, USA

³Department of Emergency Medicine, University of Pittsburgh School of Medicine, Pittsburgh, PA, USA

⁴Division of Pulmonary & Critical Care Medicine, University of Michigan School of Medicine; Ann Arbor, MA, USA

⁵Veterans Affairs Center for Clinical Management Research, Ann Arbor, Michigan, USA

Abstract

Objective—Intensive care unit (ICU) telemedicine is a novel approach for providing critical care services from a distance. We sought to study the extent of use and patterns of adoption of this technology in United States ICUs.

Design—Retrospective study combining a systematic listing of ICU telemedicine installations with hospital characteristic data from the Centers for Medicare and Medicaid Services. We examined adoption over time and compared hospital characteristics between facilities that have adopted ICU telemedicine and those that have not.

Setting—United States hospitals from 2003 to 2010.

Measurements and main results—The number of hospitals using ICU telemedicine increased from 16 (0.4% of total) to 213 (4.6% of total) between 2003 and 2010. The number of ICU beds covered by telemedicine increased from 598 (0.9% of total) to 5,799 (7.9% of total). The average annual rate of ICU bed coverage growth was 101% per year in the first four study years but slowed to 8.1% per year over the last four study years ($p < 0.001$ for difference in linear trend). Compared to non-adopting hospitals, hospitals adopting ICU telemedicine were more likely to be large (percentage with >400 beds: 11.1% vs. 3.7%, $p < 0.001$), teaching (percentage with resident coverage: 31.4% vs. 21.9%, $p = 0.003$) and urban (percentage located in metropolitan statistical areas with over one million residents: 45.3% vs. 30.1%, $p < 0.001$).

Conclusions—ICU telemedicine adoption was initially rapid but recently slowed. Efforts are needed to uncover the barriers to future growth, particularly regarding the optimal strategy for using this technology most effectively and efficiently.

Contact: Jeremy M. Kahn, MD MS, Associate Professor of Critical Care and Health Policy & Management, University of Pittsburgh, Scaife Hall, Room 602-B, 3550 Terrace Street, Pittsburgh, PA 15221, phone: 412.683.7601, kahnjm@upmc.edu.

Disclosures: Dr. Kahn received consulting fees from the US Department of Veterans Affairs on matters concerning ICU telemedicine, and has received in-kind research support from the Cerner Corporation. There are no other relevant financial conflicts to disclose.

The remaining authors have disclosed that they do not have any potential conflicts of interest.

Keywords

telemedicine; critical care; intensive care units; rural hospitals

Introduction

Intensive care unit (ICU) telemedicine uses audio-visual technology to provide critical care services from a remote location (1, 2). In its most common form, ICU telemedicine consists of remote monitoring of ICU patients using fixed installations, either continuously or during nighttime hours (3). Telemedicine can potentially improve ICU outcomes by increasing access to the expertise of dedicated intensivist physicians (4), facilitating early recognition of physiological deterioration (5), and prompting bedside providers to implement routine evidence-based practices (6). Yet studies evaluating the effect of telemedicine on ICU outcomes show mixed results, with some studies showing significant improvements in mortality and others showing no benefit (7). In addition, there are major organizational barriers to the broad adoption of ICU telemedicine, including the high technological and staffing costs, as well as a lack of consensus about how and where it is best applied (8).

Given these tensions, we sought to understand the patterns of ICU telemedicine adoption and implementation in the United States. In particular, we examined both the pace of adoption and the degree to which telemedicine has been preferentially adopted in small, rural hospitals where it may have the greatest potential to improve outcomes (9-11). Although ICU telemedicine was first described in the 1970's (12), modern applications were not introduced until 2000 and meaningful adoption did not begin until 2003 (13). Beginning in that year we linked information on ICU telemedicine use (14) to publically available hospital-level data from the Centers for Medicare & Medicaid Services, examining the rate of ICU telemedicine adoption, the geographic distribution of existing installations and the hospital characteristics associated with adoption.

Methods

Data sources

Information on ICU telemedicine adoption was obtained from a December 2010 report by the New England Health Care Institute (NEHI) and the Massachusetts Technology Collaborative (14). As part of this report, NEHI developed a comprehensive list of all ICU telemedicine installations in the United States. The goal of this list was an enumeration of all ICUs covered by telemedicine. Central hubs, from which the monitoring was performed, were not included unless that facility also had covered ICU beds. This list also did not list ICU telemedicine installations that involved only periodic consultation or robotic telepresence—although this type of telemedicine is increasing in use, the extent of its adoption in the ICU setting is unknown (15).

To obtain the list NEHI convened a working group of representatives from critical care professional societies, manufacturers of commercial ICU telemedicine systems and early-adopting health systems with knowledge of current use. Working group members created the initial list of known installations. NEHI staff mapped this list to the American Hospital Association Annual Survey, and then contacted each program to determine the number and location of hospitals with ICUs covered by telemedicine, as well as the calendar year in which each program began. Content experts in ICU telemedicine and hospital organization reviewed the list for accuracy and completeness. The final list contained 46 telemedicine programs at 249 hospitals.

Information on US hospitals was obtained from the Centers for Medicare & Medicaid Services (CMS). We used two CMS data sources: the Healthcare Cost Reporting Information System (HCRIS) and the Medicare Provider Analysis and Review (MedPAR) file. HCRIS is a hospital-level data file containing basic characteristics on all non-federal US hospitals, including street address, ownership status and bed counts. MedPAR is a patient-level data file containing the final action claims of all fee-for-service Medicare beneficiaries. We limited the analysis to only general acute care hospitals and critical access hospitals, as identified in HCRIS.

We linked the hospitals in the NEHI report to hospitals in the CMS data by hospital name, city and state and year. We linked hospitals through 2010, the year in which the NEHI report ended and the most recent year of CMS data available. Hospitals were linked only when they had ICU beds covered by telemedicine, and not if they only served as the originating site (i.e. the “hub”). In cases when a hospital could not be matched exactly by name, city and state, we contacted the hospital to determine its identification in the CMS data files. From the NEHI list we excluded two programs in the Veterans Affairs Health System, since hospitals in these programs are not present in CMS data.

Variables

We used HCRIS and MedPAR to derive hospital-level variables along two domains: structural characteristics (e.g. measures of size, location and teaching status) and technological capacity (i.e. measures of overall capacity to care for ICU patients). Structural characteristics were obtained directly from HCRIS. These included hospital size (<100 beds, 100 to 400 beds, or >400 beds) (16); number of ICU beds; ownership (non-profit, for profit, or government, i.e. hospitals owned by a municipality, county, state or other governmental institution); teaching status by resident-to-bed ratio (non-teaching: ratio = 0, small teaching: ratio >0 and <0.25, large teaching = 0.25) (17); US Census region by state (Northwest, Midwest, South or West); and urban/rural status by metropolitan statistical area classification of the hospital's ZIP code (non-metropolitan, or metropolitan with a population of <100,000, 100,000 to 1 million, or >1 million). We also calculated regional ICU competition using the Herfindahl-Hirschman Index, a econometric measures of market competition equal to the sums of squares of market share within regions (18). We defined regions using Dartmouth Atlas Hospital Referral Regions (HRRs), and calculated market share based on the number of ICU beds per hospital divided by the number of total ICU beds in each hospital's HRR (19).

Technological capacity variables were obtained from MedPAR by first identifying fee-for-service Medicare beneficiaries at each hospital receiving 11 procedures using validated *International Classification of Diseases, version 9, Clinical Modification* procedure codes. We focused on procedures that either represented a scarce technological resource or are commonly associated with admission to an ICU, including neurosurgery, cerebral arteriogram, magnetic resonance imaging, peripheral arteriovenogram, liver transplant heart or lung transplant, bone-marrow transplant, esophageal cancer resection, lung cancer resection, coronary artery bypass graft surgery, and percutaneous transluminal coronary angioplasty (20-22). To avoid misspecification due to miscoding, we only considered a hospital to provide that service if at least 10 patients in that hospital received a procedure-specific code in a calendar year.

Analysis

To examine temporal trends in ICU telemedicine adoption, for each study year we calculated the number of hospitals using ICU telemedicine and the number of ICU beds in hospitals covered by telemedicine, both as absolute counts and as proportion of the total. For

the ICU beds analysis, we made the assumption that hospitals using ICU telemedicine had all their ICU beds covered. We used Poisson regression to test the statistical significance of observed linear trends. To examine the geographic distribution of hospitals adopting telemedicine, we created year-specific density maps based on the proportion of ICU beds within the HRR covered by telemedicine with superimposed markers indicating the exact location of each adopting hospital (23). For this analysis we selected three years (2003, 2006 and 2009) representing even time intervals in our study period.

To examine hospital characteristics and procedural utilization according to telemedicine status, we compared each variable across groups using 2006 data, representing the midpoint of the study period. We used t-tests, chi-square tests, Fisher's exact tests and Wilcoxon rank-sum tests to test the statistical significance of observed differences, as appropriate. We performed two comparisons. First, we compared hospitals that have adopted telemedicine during the study period to those that have not. Second, among facilities adopting telemedicine we compared hospitals that adopted telemedicine early in the study period (2003 to 2006) to those that adopted telemedicine late in the study period (2007 to 2010), based upon the study midpoint.

Data management and statistical analyses were performed using Stata version 11.0 (StataCorp, College Station, TX). Geographic analyses were performed using ArcGIS (ESRI, Redlands, CA). This research was reviewed and approved by the University of Pittsburgh Institutional Review Board.

Results

A total of 4,760 hospitals were open at any time during the study period and were included in the final analysis. Of these, 5 hospitals had already adopted ICU telemedicine by 2003 (the actual year of adoption was 2000) and an additional 218 adopted ICU telemedicine at some point from 2003 to 2010, for a total of 223 adopting hospitals. Ten hospitals withdrew the technology during the study period. Overall the number of US hospitals with ICU telemedicine increased from 16 (0.4%) in 2003 to 213 (4.6%) in 2010 ($p<0.001$ for temporal trend), for an average annual increase of 61.0% per year (Figure 1a). However, most of that growth occurred during the first four years of the study period (average annual rate of growth: 132.3% per year) compared to the last four years (average annual rate of growth: 8.4% per year) ($p<0.001$ for difference in growth rate between time periods).

The overall number of ICU beds covered by telemedicine increased from 598 (0.4%) in 2003 to 5,799 (7.9%) in 2010 ($p<0.001$ for temporal trend), for an average annual growth rate of 48.0% per year (Figure 1b). Most of that growth occurred during the first four years of the study period (average annual rate of growth: 101.1% per year) compared to the last four years (average annual rate of growth: 8.1% per year) ($p<0.001$ for difference in growth rate between time periods). The geospatial distribution of ICU telemedicine coverage over time is shown in Figure 2. Of 306 HRRs in the US, 3 (1.0%) had a hospital with telemedicine in 2003, increasing to 204 (66.7%) in 2009. Initial adoption was located on the East and West coasts, although over time there was no clear regional predominance.

Hospital characteristics associated with ICU telemedicine adoption are shown in Table 1. Compared to hospitals without ICU telemedicine, hospitals with ICU telemedicine were more likely to be large, non-profit, teaching hospitals located in large metropolitan statistical areas. Conversely, hospitals that did not adopt telemedicine were more likely to be small, for-profit, non-teaching hospitals in rural areas. There were no differences in the regional ICU competition index between adopters and non-adopters. Hospitals without telemedicine were less well resourced with regards to major technologies and procedures.

Hospital characteristics associated with early (2003 to 2006) versus late (2007 to 2010) adoption are shown in Table 2. Generally hospitals in both groups were similar, although later adopters were more likely to be smaller than early adopters.

Discussion

Using a systematic accounting of ICU telemedicine in the United States linked to federal data we found a substantial expansion of ICU telemedicine from 2003 to 2010. This increase was most rapid immediately following the introduction of commercial programs in 2000 and the publication of an early study demonstrating significant mortality reductions and cost savings associated with the technology (13). However, the rate of increase slowed in more recent years, with few new installations in the latter part of the study period.

One way to interpret the slowing growth of ICU telemedicine is to infer that the technology has reached the saturation point, consistent with the classic Rogers model of diffusion of innovation (24). Under this model, the growth of ICU telemedicine is expected to plateau as late adopters and laggards adopted the technology, and further expansion would be unlikely. This pattern would suggest that the existing barriers to further diffusion are quite substantial, limiting ICU telemedicine's potential applicability at less than 10% of all ICU beds. An alternative model might be the “tipping point” concept, in which an innovation is adopted at a linear rate until novel contextual factors drive additional rapid adoption (25). Under this model additional expansion may yet occur if current barriers are reduced and more compelling data create a clear sense of perceived usefulness among relevant decision-makers.

Our study underscores the fact that there are substantial barriers to telemedicine adoption that must be addressed prior to further adoption. The primary barrier is costs—the cost of a telemedicine program exceeds \$3 million annually and are not easily borne by hospitals that are already observing declines in revenue (26). Some experts have posited that these expenditures may be regained by reductions in ICU length of stay and prevention of ICU-acquired complications (13). However, these positive effects are not assured, and the true cost savings associated with reductions in ICU length of stay may not be large enough to meaningfully affect a hospital's bottom line (27). Another source of cost recovery would be for physicians to bill for telemedicine services. Although physician reimbursement for telemedicine services is increasingly common (28, 29) few payers currently reimburse for critical care services provided via telemedicine, given the importance of bed-side assessment in the ICU as well as concerns about overutilization and a resultant devaluation of critical care services (30).

Another key barrier is the perception of telemedicine on the part of bedside practitioners, especially nurses who may be doubtful of the potential benefits and concerned about disruptions in daily workflow associated with remote monitoring (31). Lastly, there are reasonable questions of efficacy given the low quality of the literature and the number of negative studies (7). In support of this notion are several studies calling into question the benefits of nighttime intensivist staffing (32, 33). These studies suggest that routine processes of care are more important than nighttime staffing by bedside or remote providers.

We found that a minority of adopting hospitals were small (i.e. <100 beds) and rural (i.e. located in a non-metropolitan area). These findings suggest that ICU telemedicine is only partly fulfilling its promise as strategy to extend the benefits of intensivist physicians to patients in small, rural hospitals. Currently the vast majority of hospitals in the US do not have trained intensivist physicians (9). Although telemedicine has great potential to improve the quality of critical care in these hospitals, it appears that a substantial proportion of

adoption is occurring in large, urban hospitals that are already well resourced. It is possible that small, rural hospitals are finding other approaches to dealing with severely ill patients, such as through transfers to higher levels of care or quality improvement cooperatives (34). It is also possible that, contrary to intuition, large, urban hospitals are the most appropriate hospitals types for ICU telemedicine. This might be true if telemedicine improves outcomes at hospitals with extremely high acuity, even in the setting of high-quality bedside care.

These adoption patterns may also be a reflection of the varying reasons that hospitals adopt ICU telemedicine. In particular, there are two ways that ICU telemedicine can enter a health care market: through the initial introduction of a telemedicine “hub” and through the subsequent addition of new “spokes” onto an existing hub. It may be that these different forms of adoption have different barriers and facilitators. For example, initial introduction of a hub may be the result of an academic medical center's desire to invest in new infrastructure and community outreach, regardless of return on investment. Conversely, subsequent expansion into spoke hospitals may depend more strongly on local conditions, with adoption predicated on the availability of a hub site and potential return on investment playing a larger role. Thus it may be that although we observed preferential adoption in large, urban hospitals, this adoption is only a necessary precedent to more rapid adoption in small rural hospitals. Indeed, we show that later adopting hospitals are generally smaller than early adopting hospitals, suggesting that future growth may come by expanding the reach of existing hubs rather than the creation of new hubs.

Additional research is needed to best define the ideal use of this potentially transformative technology. As noted in a recent federally sponsored consensus conference on the research agenda in critical care telemedicine, the key questions are not whether this technology should be applied, but where and how it can be applied most effectively and efficiently (35). Research is needed to determine the settings in which telemedicine technology is most effective and the organizational factors that are associated with its success and failure. For example, studies could compare the effectiveness of telemedicine programs in ICUs with varying case-mix and multidisciplinary staffing patterns. Without this research we risk investing in monitoring technology that, like previous monitoring technologies in the ICU such as the pulmonary artery catheter, fail to improve care on average and are ultimately abandoned (36).

Our study has several limitations. First, although we used the most comprehensive listing of existing telemedicine programs to date, it is possible that this list was incomplete. However, NEHI took several major steps to ensure the accuracy and completeness of their listing. Second, because we based our analysis on the NEHI report we only included ICU telemedicine programs that consisted of comprehensive remote monitoring. Period consultation via robotic telepresence, as is sometimes used in the emergency department or neuro-critical care setting, was not included in our analysis (37). We suspect that the issues surrounding adoption of robotic telemedicine models differ substantially from the issues surrounding continuous remote monitoring, warranting a separate study. Third, our study only includes programs through 2010, the most recent year of complete CMS data. It is possible that adoption trends have changed since that time. It is also possible that the adoption trends we observed were influenced by the overall US economy, which entered recession in 2009, and thus are reflective of health care growth as a whole rather than issues specific to ICU telemedicine. Fourth, we assumed that hospitals using telemedicine use it in all their ICU beds and that ICU beds associated with a command center came live when the command center came live. These assumptions may not be true, particularly in large hospitals with multiple ICUs. Thus we may have slightly overestimated the extent of ICU telemedicine adoption in the United States or attributed some adoption to earlier than it

actually occurred. However, the given the limited overall adoption we observed, the extent of this error is likely minor.

Conclusions

Future effectiveness research and future technological innovations that reduce its cost may change the adoption patterns of ICU telemedicine we observed, facilitating its adoption in more hospitals and more small, rural facilities. Until then, we demonstrate that the adoption of this innovative approach to critical care delivery appears to have slowed.

Acknowledgments

The authors gratefully acknowledge the assistance of Wendy Everette, ScD from NEHI for her assistance in providing the details and methodology of the NEHI report.

This work was performed at the University of Pittsburgh.

No reprints will be ordered.

Financial support: none.

Dr. Kahn's institution received grant support from the National Institutes of Health, Health Resources and Services Administration (current and pending grants to study the organization of ICU care, including ICU telemedicine). Dr. Wallace received grant support (NHLBI K12). Dr. Khan received support for travel from National Association of Long-Term Acute Care Hospitals.

Dr. Wallace is employed by the University of Pittsburgh. Dr. Kahn consulted for the US Department of Veterans Affairs (regarding the use of ICU telemedicine).

References

1. Garland A, Gershengorn HB. Staffing in ICUs: physicians and alternative staffing models. *Chest*. 2013; 143:214–221. [PubMed: 23276844]
2. Breslow MJ. Remote ICU care programs: current status. *J Crit Care*. 2007; 22:66–76. [PubMed: 17371749]
3. Lilly CM, Fisher KA, Ries M, et al. A national ICU telemedicine survey: validation and results. *Chest*. 2012; 142:40–47. [PubMed: 22518025]
4. Pronovost PJ, Angus DC, Dorman T, et al. Physician staffing patterns and clinical outcomes in critically ill patients: a systematic review. *JAMA*. 2002; 288:2151–2162. [PubMed: 12413375]
5. Siebig S, Kuhls S, Imhoff M, et al. Collection of annotated data in a clinical validation study for alarm algorithms in intensive care--a methodologic framework. *J Crit Care*. 2010; 25:128–135. [PubMed: 19327311]
6. Weiss CH, Moazed F, McEvoy CA, et al. Prompting physicians to address a daily checklist and process of care and clinical outcomes: a single-site study. *Am J Respir Crit Care Med*. 2011; 184:680–686. [PubMed: 21616996]
7. Wilcox ME, Adhikari NK. The effect of telemedicine in critically ill patients: systematic review and meta-analysis. *Crit Care*. 2012; 16:R127. [PubMed: 22809335]
8. Berenson RA, Grossman JM, November EA. Does Telemonitoring Of Patients--The eICU--Improve Intensive Care? *Health Affairs*. 2009; 28:w937–w947. [PubMed: 19696068]
9. Angus DC, Shorr AF, White A, et al. Critical care delivery in the United States: distribution of services and compliance with Leapfrog recommendations. *Crit Care Med*. 2006; 34:1016–1024. [PubMed: 16505703]
10. Kahn JM, Goss CH, Heagerty PJ, et al. Hospital volume and the outcomes of mechanical ventilation. *N Engl J Med*. 2006; 355:41–50. [PubMed: 16822995]
11. Freeman VA, Walsh J, Rudolf M, et al. Intensive care in critical access hospitals. *J Rural Health*. 2007; 23:116–123. [PubMed: 17397367]

12. Grundy BL, Crawford P, Jones PK, et al. Telemedicine in critical care: An experiment in health care delivery. *Journal of the American College of Emergency Physicians*. 1977; 6:439–444. [PubMed: 71365]
13. 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; 32:31–38. [PubMed: 14707557]
14. Fifer, S.; Everett, W.; Adams, M., et al. *Critical care, critical choices, the case for tele-ICUs in intensive care*. Cambridge: New England Health Care Institute and Massachusetts Technology Collaborative; 2010.
15. Rogove HJ, McArthur D, Demaerschalk BM, et al. Barriers to telemedicine: survey of current users in acute care units. *Telemed J E Health*. 2012; 18:48–53. [PubMed: 22082107]
16. Jha AK, DesRoches CM, Campbell EG, et al. Use of electronic health records in U.S. hospitals. *N Engl J Med*. 2009; 360:1628–1638. [PubMed: 19321858]
17. Prasad M, Iwashyna TJ, Christie JD, et al. Effect of work-hours regulations on intensive care unit mortality in United States teaching hospitals. *Crit Care Med*. 2009; 37:2564–2569. [PubMed: 19623042]
18. Phibbs CS, Robinson JC. A variable-radius measure of local hospital market structure. *Health Serv Res*. 1993; 28:313–324. [PubMed: 8344822]
19. Dartmouth atlas of health care [Internet]. Chicago: American Hospital Publishing, Inc; 1996. Available from: <http://www.dartmouthatlas.org/downloads/atlas/96Atlas.pdf>
20. Quan H, Parsons GA, Ghali WA. Validity of Procedure Codes in International Classification of Diseases, 9th revision, Clinical Modification Administrative Data. *Medical care*. 2004; 42:801. [PubMed: 15258482]
21. Udvarhelyi IS, Gatsonis C, Epstein AM, et al. Acute myocardial infarction in the Medicare population Process of care and clinical outcomes. *JAMA*. 1992; 268:2530–2536. [PubMed: 1404820]
22. Finlayson EVA, Goodney PP, Birkmeyer JD. Hospital volume and operative mortality in cancer surgery: a national study. *Arch Surg*. 2003; 138:721–5. discussion 726. [PubMed: 12860752]
23. Brewer CA, Pickle L. Evaluation of methods for classifying epidemiological data on choropleth maps in series. *Annals of the Association of American ...*. 2003
24. Berwick DM. Disseminating innovations in health care. *JAMA*. 2003; 289:1969–1975. [PubMed: 12697800]
25. Gladwell, M. *The tipping point: how little things can make a big difference*. Boston: Little, Brown and Co; 2000.
26. Kumar G, Falk DM, Bonello RS, et al. The costs of critical care telemedicine programs: a systematic review and analysis. *Chest*. 2012
27. Kahn JM, Rubenfeld GD, Rohrbach J, et al. Cost savings attributable to reductions in intensive care unit length of stay for mechanically ventilated patients. *Medical care*. 2008; 46:1226–1233. [PubMed: 19300312]
28. Brown NA. State Medicaid and private payer reimbursement for telemedicine: An overview. *J Telemed Telecare*. 2006; 12(Suppl 2):S32–9. [PubMed: 16989672]
29. Whitten P, Buis L. Private payer reimbursement for telemedicine services in the United States. *Telemed J E Health*. 2007; 13:15–23. [PubMed: 17309350]
30. Hoffmann S. Should tele-ICU services be eligible for professional fee billing? *Chest*. 2011; 140:849–51. discussion 851–2. [PubMed: 21972380]
31. Mullen-Fortino M, DiMartino J, Entrikin L, et al. Bedside nurses' perceptions of intensive care unit telemedicine. *Am J Crit Care*. 2011; 21:24–31. quiz 32. [PubMed: 22210696]
32. Wallace DJ, Angus DC, Barnato AE, et al. Nighttime intensivist staffing and mortality among critically ill patients. *N Engl J Med*. 2012; 366:2093–2101. [PubMed: 22612639]
33. Kerlin MP, Small DS, Cooney E, et al. A Randomized Trial of Nighttime Physician Staffing in an Intensive Care Unit. *N Engl J Med*. 2013
34. Iwashyna TJ, Christie JD, Moody J, et al. The structure of critical care transfer networks. *Medical care*. 2009; 47:787–793. [PubMed: 19536030]

35. Kahn JM, Hill NS, Lilly CM, et al. The research agenda in ICU telemedicine: a statement from the Critical Care Societies Collaborative. *Chest*. 2011; 140:230–238. [PubMed: 21729894]
36. Rubenfeld GD, McNamara-Aslin E, Robinson L. The pulmonary artery catheter, 1967-2007: rest in peace? *JAMA*. 2007; 298:458–461. [PubMed: 17652302]
37. Vespa PM, Miller C, Hu X, et al. Intensive care unit robotic telepresence facilitates rapid physician response to unstable patients and decreased cost in neurointensive care. *Surg Neurol*. 2007; 67:331–337. [PubMed: 17350395]

Figure 1. Utilization of intensive care unit (ICU) telemedicine by year expressed as percentages of all United States hospitals (panel A) and percentages of United States ICU beds (panel B).

Figure 2.

Geographic distribution of intensive care unit (ICU) telemedicine. The circles indicate hospitals with ICU telemedicine, with the size of the markers proportional to the number of intensive care beds for each hospitals. The markers are overlaid onto Dartmouth Atlas hospital referral regions, which are shaded according to the proportion of covered ICU beds in the region.

Table 1
Hospital characteristics by intensive care unit telemedicine status

Variable	ICU telemedicine (n=223)	No ICU telemedicine (n=4,537)	P-value
Hospital size			
<100 beds	85 (38.1%)	2,688 (59.3%)	<0.001
100 to 400 beds	113 (50.7%)	1,689 (37.1%)	
>400 beds	25 (11.1%)	167 (3.7%)	
ICU beds	15 [6 -33]	7 [0 – 20]	<0.001
Ownership			
Non-profit	203 (91.0%)	2,497 (55.0%)	<0.001
For-profit	15 (6.7%)	900 (19.8%)	
Government	5 (2.2%)	1,140 (25.1%)	
Teaching status			
Non-teaching	153 (68.6%)	3,547 (78.2%)	0.003
Small teaching	45 (20.2%)	652 (14.4%)	
Large teaching	25 (11.2%)	338 (7.5%)	
Region			
Northeast	20 (9.0%)	596 (13.1%)	<0.001
Midwest	111 (49.8%)	1,291 (28.5%)	
South	47 (21.1%)	1,791 (39.5%)	
West	45 (20.2%)	859 (18.9%)	
Metropolitan statistical area size			
Non-MSA	28 (12.6%)	1218 (26.8%)	<0.001
<100,000K	31 (13.9%)	727 (16.0%)	
100K to 1 million	63 (28.3%)	1,228 (27.1%)	
> 1 million	101 (45.3%)	1,364 (30.1%)	
Competition index *	1521 [1019 – 2709]	1476 [865 – 2758]	0.53
ICU-related procedures [†]			
Neurosurgery	83 (37.2%)	942 (20.8%)	<0.001
Cerebral arteriogram	126 (56.5%)	1,478 (32.6)	<0.001
Magnetic resonance imaging	37 (16.6%)	627 (13.8%)	0.73
Peripheral arteriovenogram	143 (64.1%)	1,934 (42.7%)	<0.001
Liver transplant	2 (1.0%)	58 (1.3%)	0.68
Heart or Lung Transplant	5 (2.4%)	35 (0.8%)	0.02
Bone marrow transplant	3 (1.4%)	50 (1.1%)	0.74
Esophageal cancer resection	6 (2.7%)	64 (1.4%)	0.12
Lung cancer resection	62 (27.8%)	549 (12.1%)	<0.001
CABG surgery	90 (40.4%)	1,009 (22.4%)	<0.001
PTCA	117 (52.5%)	1,229 (28.6%)	<0.001
Any ICU related procedure	148 (66.4%)	2,022 (44.6%)	<0.001

Values are median [interquartile range] or frequency (percent).

ICU = intensive care unit; CABG = coronary artery bypass graft; PTCA = percutaneous transluminal coronary angioplasty

* The Herfindahl-Hirschman Index, an econometric measure of market competition ranging from 1 to 10,000, with higher scores indicating more market competition.

[†] Procedures are not mutually exclusive.

Table 2

Hospital characteristics by ICU telemedicine adoption stage.

Variable	Adopted 2003 to 2006 (n=160)	Adopted 2007 – 2010 (n=63)	P-value
Hospital size			
<100 beds	66 (41.3%)	19 (30.2%)	0.05
100 to 400 beds	73 (45.6%)	40 (63.5%)	
>400 beds	21 (13.1%)	4 (6.4%)	
ICU beds	13 [6 -33]	22 [6 – 32]	0.13
Ownership			
Non-profit	147 (91.9%)	56 (88.9%)	0.58
For-profit	9 (5.6%)	6 (9.5%)	
Government	4 (2.5%)	1 (1.6%)	
Teaching status			
Non-teaching	110 (68.8%)	43 (68.3%)	0.44
Small teaching	30 (18.8%)	15 (23.8%)	
Large teaching	20 (12.5%)	5 (7.9%)	
Region			
Northeast	18 (8.5%)	2 (3.2%)	0.11
Midwest	78 (48.8%)	33 (52.4%)	
South	36 (22.5%)	11 (17.5%)	
West	28 (17.5%)	17 (27.0%)	
Metropolitan statistical area size			
Non-MSA	24 (15.0%)	4 (6.4%)	0.15
<100,000K	20 (12.5%)	11(17.5%)	
100K to 1 million	41 (25.6%)	22 (34.9%)	
> 1 million	75 (46.9%)	26 (41.3.4%)	
Competition index *	1521 [1019 – 2968]	1339 [865 – 2396]	0.37

Values are median [interquartile range] or frequency (percent).

ICU = intensive care unit

* The Herfindahl-Hirschman Index, an econometric measure of market competition ranging from 1 to 10,000, with higher scores indicating more market competition.