The Research Agenda in ICU Telemedicine

A Statement From the Critical Care Societies Collaborative

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ICU telemedicine uses audiovisual conferencing technology to provide critical care from a remote location. Research is needed to best define the optimal use of ICU telemedicine, but efforts are hindered by methodological challenges and the lack of an organized delivery approach. We convened an interdisciplinary working group to develop a research agenda in ICU telemedicine, addressing both methodological and knowledge gaps in the field. To best inform clinical decision-making and health policy, future research should be organized around a conceptual framework that enables consistent descriptions of both the study setting and the telemedicine intervention. The framework should include standardized methods for assessing the preimplementation ICU environment and describing the telemedicine program. This framework will facilitate comparisons across studies and improve generalizability by permitting context-specific interpretation. Research based on this framework should consider the multidisciplinary nature of ICU care and describe the specific program goals. Key topic areas to be addressed include the effect of ICU telemedicine on the structure, process, and outcome of critical care delivery. Ideally, future research should attempt to address causation instead of simply associations and elucidate the mechanism of action in order to determine exactly how ICU telemedicine achieves its effects. ICU telemedicine has significant potential to improve critical care delivery, but high-quality research is needed to best inform its use. We propose an agenda to advance the science of ICU telemedicine and generate research with the greatest potential to improve patient care. *CHEST 2011; 140(1):230–238*

Telemedicine is a strategy for improving the quality of health care through the electronic transfer of medical information through interactive audiovisual tools.[1] Increasingly, hospitals are using telemedicine as a quality improvement strategy in the ICU.[2] With ICU telemedicine, clinicians can remotely monitor patient vital signs, physiologic status, and laboratory studies and assist bedside providers in interventions when appropriate. Given the current need for additional critical care services, limitations of the existing workforce, and access issues related to geography, the use of telemedicine in critical care is likely to expand in the coming years.[3,4] However, relatively little research has been directed at understanding the clinical and financial implications of telemedicine in critical care or potential unintended consequences. High-quality research is needed to ensure that the potential value of telemedicine for patients, the health-care system, and society is achieved.[5]

To provide a conceptual and practical framework for ICU telemedicine research, we convened an interdisciplinary workgroup comprising experts in critical care delivery, telemedicine delivery, organizational science, health services research, and health-care policy. Our goals were to examine the state of the science underlying ICU telemedicine, identify key methodological and knowledge gaps, and develop a focused agenda for future research.

Methods

A statement on the research agenda in ICU telemedicine was developed by a working group sponsored by the Critical Care Societies Collaborative, which includes the American Association of Critical-Care Nurses, the American College of Chest Physicians, the American Thoracic Society, and the Society of Critical Care Medicine. The working group was funded by a grant from the Agency for Health Research and Quality. Participants were identified by the working group chairs to represent stakeholders within the fields of medical and surgical critical care, critical care nursing, critical care pharmacy, health-care economics, health services research, rural health research, information technology, and organizational science.

The working group convened a 2-day conference from March 24, 2010, to March 25, 2010, at the headquarters of the American College of Chest Physicians in Northbrook, Illinois. The goals of the conference were to review the existing research in ICU telemedicine, identify key methodological and knowledge gaps, and develop an agenda for future research. Prior to the conference, the working group chairs developed a literature summary for distribution to the conference participants. We searched the English-language literature using Medline and the Google Scholar search engine using the search terms "intensive care" or "critical care" and "telemedicine." Titles and abstracts were reviewed to identify peer-reviewed original research articles describing remote delivery of critical care services through audiovisual technology. Published articles meeting these criteria[6-25] were summarized into six categories: study design, setting, telemedicine system design, patients, time period, and primary findings (e-Appendix 1).

The working group defined ICU telemedicine as a system to facilitate the remote delivery of critical care services using interactive audio, video, and electronic links. This definition could apply to services ranging from continuous electronic surveillance by an offsite team of clinicians providing interactive care for broad populations of patients to intermittent assessment and management of patients with specific clinical conditions. The group did not consider more general remote interventions, such as telephone consultation, distance-based quality improvement, or medical education, to constitute ICU telemedicine.

The conference consisted of a series of breakout groups followed by plenary discussions during which group leaders summarized and reported conclusions to the entire working group for discussion and feedback. Each group was assigned to discuss one of six specific content areas related to the evaluation of ICU telemedicine: clinical outcomes, process of care, costs and cost-effectiveness, patient safety, organizational culture, and medical education. The resulting statement is organized into a critique of the existing literature, a methodological research agenda (ie, methods that will advance the science of ICU telemedicine research), and a content-based research agenda (ie, research that will address specific knowledge gaps). The statement was drafted by a designated writing committee on the basis of the conference proceedings and then circulated to conference participants for revision using an iterative process. The final document was approved by the leadership of all four organizing specialty societies. Complete disclosure statements for all conference participants are available in e-Appendix 2.

Results

Limitations of the Existing Literature

A number of published studies have attempted to evaluate the clinical and economic impact of ICU telemedicine.[6-12] Although these studies provide an important foundation for our understanding of telemedicine in critical care, they often suffer from a number of conceptual and methodological limitations. Most studies use a before-and-after study design and are subject to numerous biases, including unmeasured changes in case mix, temporal trends, coincident interventions, and random variation.[26] Additionally, ICU telemedicine often introduces multiple interventions at the same time, including audiovisual surveillance, staffing changes, decision-support tools, and new electronic medical records. Introducing multiple different interventions simultaneously makes it difficult to understand the specific mechanism of the effect. These studies also do not consistently describe the organization and management of participating ICUs prior to introducing the telemedicine program, making it difficult to put the research into clinical context.

Working group participants expressed concern about the lack of adequate interdisciplinary expertise in prior investigations. Given that critical care is itself interdisciplinary, ICU telemedicine research should involve multiple clinical and scientific disciplines.

Important clinical stakeholders include nurses, physicians, pharmacists, respiratory therapists, and social workers, among others. The research team should have expertise in health services research, epidemiology, social science, information technology, and health economics. In particular, because ICU telemedicine is an organizational intervention, strong consideration should be given to including investigators with specific expertise in organizational evaluation and the ways it differs from standard pharmacologic or epidemiologic research. Without such appropriate scientific expertise, it is unlikely that research will be able to successfully inform clinical and health policy decisions.

Improving Telemedicine Research

Recognizing these limitations, the working group stressed the need to develop a novel standardized framework, different from the framework described previously, that clinicians and researchers could use in planning, implementing, and evaluating ICU telemedicine interventions. The framework should be developed by an interdisciplinary panel drawing on a broad range of research expertise and considering the multidimensional role of telemedicine in critical care. The evaluation framework should consider and incorporate existing telemedicine evaluation frameworks as well as frameworks for evaluating other complex health interventions.[27,28] Previously developed frameworks for evaluating telemedicine outside of the ICU setting, such as the US Health Resources and Services Administration framework for evaluating telemedicine in the context of rural health (Table 1), may be a useful starting point.[29] However, no current framework is fully adequate.

The ICU telemedicine framework should have two major components: a standardized approach to assessing the preimplementation ICU environment and a standardized lexicon for defining the ICU telemedicine intervention:

- *Standardized approach to assessing the preimplementation ICU environment.* The baseline, or comparator state, is essential to understanding the impact of telemedicine as well as the factors that might influence its success. Potentially important environmental factors include a range of patient, ICU, and hospital characteristics as well as the organizational climate of the ICU (Table 2). Such a standardized approach to the environmental scan would allow those seeking to interpret and apply the research results to better understand the comparator state and, therefore, to infer similarities and differences between their own clinical context and the ICU under study. Additionally, it would elucidate factors

that may modify the uptake and effectiveness of the ICU telemedicine intervention, helping readers to interpret variation in effectiveness between studies. Finally, a well-defined comparator state would help readers to understand which quality improvement practices are in place in the ICU prior to the introduction of telemedicine. Several ICU quality improvement programs have achieved important successes without telemedicine.[30,31] Indeed, the best comparator for a comparative effectiveness study of telemedicine may be local quality improvement initiatives rather than no intervention at all.

- *Standardized lexicon for defining the telemedicine intervention.* ICU telemedicine, even with the working definitions used for this process, is a broad term that applies to a range of widely varying interventions. Researchers require a standardized lexicon to report the attributes of the ICU telemedicine intervention under study. Various components to be addressed in the lexicon may include the type of technologies comprising the system, the timing of monitoring (eg, continuous vs intermittent), the role of the ICU telemedicine clinicians (eg, emergent care, general consultation, comanagement), the training and composition of the ICU telemedicine team (eg, nurses, physicians), and the goals of the telemedicine program (eg, more timely interventions for physiologic decompensation, enhancing access to experts, increasing compliance with best practices). The definition of ICU telemedicine considered by the working group represents an appropriate starting place for this lexicon. However, the final lexicon should include sufficient detail about the process and structure of the ICU telemedicine application to allow users to exactly specify their program. This lexicon will improve generalizability by helping research users to understand exactly how ICU telemedicine was applied.

The benefits of adhering to this framework are numerous. Subsequent research will be more generalizable by allowing for context-specific interpretation and providing insight into both mechanism of action and causation. Ultimately, such research will lead to better-informed decisions about the implementation and practice of ICU telemedicine. This framework also will facilitate cross-study comparisons and future systematic reviews because each study will use a similar reporting structure. Finally, this framework will minimize ideologic and commercial bias in implementation and reporting because studies will be more transparent and reporting will be standardized across studies.

Table 1—Framework for Assessing Telemedicine

Domain	Questions
Clinical outcomes	Does telemedicine facilitate a more rapid, accurate, and effective treatment plan?
	Does telemedicine reduce morbidity and mortality?
	Does telemedicine obviate or facilitate evacuation or transport of the patient?
	Does telemedicine obviate or reduce the need for admissions, readmissions, or repeat visits for an unresolved problem?
Technical acceptability	Is the quality of information acceptable for a given clinical application?
	Is the system acceptable with regard to reliability, expandability, connectivity, safety, precision, compatibility, and interoperability?
	Is the system user friendly?
	Are the physical environment and location conducive to the efficient and effective delivery of health-care services?
Health systems interface	How does the telemedicine system fit into or change the existing workflow and communication patterns.
	What new skills and staff positions are required to manage and operate the system?
	Does telemedicine enable health systems to become more productive, more efficient, or more effective?
	Do the cognitive or communication skills and the information needed for telemedicine differ from those of conventional medicine?
Costs and benefits	What is the cost of purchasing, operating, and maintaining a given system, and is this cost sustainable?
	What are the costs and benefits associated with using telemedicine for patients, practitioners, and organizations (including effects on travel times, market share, revenues, productivity, and transport)?
Patient/provider acceptability	Do patients and practitioners believe that telemedicine is medically useful and adequate for patient care?
	Are practitioners concerned that participating in telemedicine will interrupt their normal work patterns?
Access	With telemedicine, do patients receive care that they would not have otherwise received?
	With telemedicine, are the patients seen by a health professional sooner than if telemedicine were not available?

Adapted from the Office of Rural Health Policy, Health Resources and Services Administration, US Department of Health and Human Services.[29]

Addressing Key Knowledge Gaps

The working group identified ICU telemedicine knowledge gaps in several key topic areas. We organized these gaps around the Donabedian framework for health-care quality in which quality is made up of three interrelated domains: structure, process, and outcome (Fig 1).[32] Within each domain, the working group identified several high-priority questions to be addressed by future research (Table 3).

Structure: Research is needed into the optimal organizational structure of ICU telemedicine programs, including the competing merits of various telemedicine models, such as a periodic consult model vs a continuous management model. These models may play a different and complementary role in various clinical settings. Research also is needed into the optimal make-up of the telemedicine team, core competencies of ICU telemedicine clinicians, and strategies to train clinicians in these core competencies. Working group participants also stressed the need for research that deconstructs which components of the program are most important to ensure effectiveness. Such an approach will help to elucidate the potential mechanisms of effect, making the research more useful to clinicians and administrators. To further uncover mechanisms, research should assess key subgroups of patients with varying clinical needs. For example, studying patients requiring early aggressive resuscitation (ie, trauma, sepsis) may provide insight into whether telemedicine improves the care of patients with evolving physiologic instability, whereas studying patients with chronic critical illness may provide insight into whether telemedicine works by improving use of evidence-based preventive and therapeutic strategies or by early detection of evolving physiologic changes.

Research is needed into the impact of telemedicine on the structure and organization of the ICU itself and its interaction with institutional critical care governance. The working group noted that telemedicine can transform ICU organization, affecting staffing patterns, teamwork, communication, and systems-based practice within the ICU. This transformation could be either beneficial or harmful, and research is needed into the determinants of these organizational transformations. Research is also needed into strategies to optimize organizational readiness for telemedicine prior to implementation, including how variations in baseline readiness can have an impact on the effectiveness of the telemedicine intervention.[33] For example, studies should address how telemedicine enhances or disrupts the traditional chain of command and how telemedicine enhances or disrupts the existing workflow patterns of the interdisciplinary care team. Research into organizational climate is important not only in the ICU but also in the telemedicine unit itself, where organization may have an impact on effectiveness. Key domains for climate-based research include acceptance, teamwork,

Table 2—*Potential Elements of a Standardized Preintervention Environmental Scan*

Domain	Element
Patient characteristics	Demographics
	Diagnosis mix
	Severity of illness
	Complication rates
	Best practice adherence
	Family and patient satisfaction
	Quality of end-of-life care
ICU characteristics	ICU type (surgical, medical, etc)
	Degree of specialization
	Physician staffing model
	Nursing staffing ratio
	Allied health professional staffing
	Interdisciplinary rounding model
	Quality of care
	Hand-off practices
	Medical and nursing leadership
Hospital characteristics	University affiliation
	Teaching status
	Information technology utilization
	Health system affiliation/integration
Community characteristics	Population size
	Metropolitan setting (urban vs rural)
	Payer mix
Organizational context	Readiness for change
	Safety climate
	Team climate
	Resiliency
	Critical care governance structure
	Health-care system quality and safety

communication, trust, and level of engagement.[34] Acceptance research is especially important because acceptance of new technology cannot be assumed and yet is essential for successful adoption.[35]

Process: Research is needed into the process of ICU telemedicine, including strategies to optimize the delivery of critical care through telemedicine. Such research should address methods to improve the usability and workflow of telemedicine applications,[23] methods to improve the quality of the telemedicine recommendations (appropriateness, timeliness, and effectiveness), and methods by which innovation in ICU telemedicine occurs. Research also is needed into the effect of ICU telemedicine on processes of care at the bedside, including evidence-based prac-
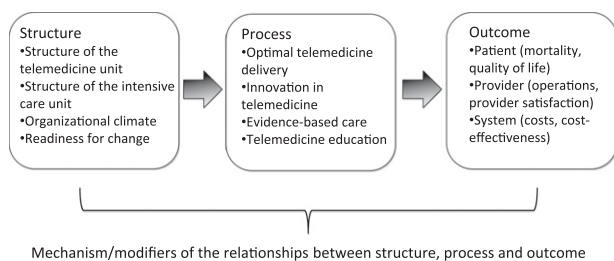
FIGURE 1. Proposed framework for ICU telemedicine evaluation based on the Donabedian quality framework.

tices, responses to alerts and alarms, guideline adherence, and protocol usage. This research should focus on ICU patients for whom evidence-based practices exist, such as in those with acute lung injury and sepsis.[36] When the evidence is not strong, researchers should attempt to identify areas in which evidence needs to be built. Research investigating processes of care also should address potential unintended consequences of telemedicine, such as reductions in bedside nurse vigilance.

Additionally, process-centered research should study the relationship between telemedicine and the process of medical education. Research is needed into the effect of telemedicine on undergraduate, graduate, and continuing education in the ICU and should include strategies for developing and testing an educational curriculum around ICU telemedicine. Current medical training emphasizes education with bedside care but may neglect education in distance-based care; thus, future research should be directed at determining the core competencies of an ICU telemedicine clinician and strategies to provide these competencies. Research also is needed into the capacity for telemedicine to provide off-hours education and support for nurses and physicians in training.

Outcomes: Research is needed into the effect of telemedicine on critical care outcomes from the perspective of the patient, the provider, the health-care system, and those responsible for paying for care. The most important patient-centered outcome is mortality, specifically risk-adjusted mortality tied to discrete time periods rather than in-hospital mortality that can be biased by discharge practices.[37] Research also should consider the effect of telemedicine on other patient-centered outcomes, including discharge location, health-related quality of life, end-of-life care, and patient and family satisfaction. From the provider perspective, research should address hospital operational outcomes such as length of stay, readmission rate, case volume, patient throughput, ICU bed availability, and interhospital transfers (both rate and timing). Because telemedicine could either increase or decrease transfer rates, both of which may be beneficial, studies of transfer rates also should evaluate mortality. Research should address quality of life among care providers as well, including job satisfaction and burnout.

Patient safety is a key outcome domain from both the patient and the provider perspective. Research is needed into how ICU telemedicine can be used to prevent medical errors and complications. Such research could be directed at the safety effects of ICU telemedicine on routine care (ie, central venous catheter placement, medication administration), surveillance for complications (ie, self-extubation), and

Special Features

Domain	Topic Area	Potential Research Questions
Structure	Telemedicine unit	What is the optimal telemedicine model for different clinical settings?
		What individual components of telemedicine are most important to ensure efficacy?
		What is the optimal make-up of the telemedicine team?
		What are the core competencies of an ICU telemedicine clinician, and how can these be taught?
	ICU	How does ICU telemedicine alter physician, nurse, and ancillary staffing patterns at the bedside?
		How can ICU organizational readiness be optimized prior to introducing a telemedicine program?
	Organizational climate	How does organizational climate, both within the ICU and within the telemedicine unit, modify the success of the program?
		In what ways does telemedicine enhance or disrupt the interdisciplinary ICU team?
	Readiness for change	What are the organizational barriers to telemedicine adoption?
		What factors influence acceptance of ICU telemedicine by bedside clinicians?
Process	Telemedicine delivery	How do we measure and improve telemedicine workflow and usability?
		What factors influence the quality of the clinical recommendations by telemedicine clinicians?
		How does communication effectiveness influence uptake of telemedicine recommendations?
		What factors determine innovation in ICU telemedicine?
	Evidence-based ICU practice	How can telemedicine be used to improve evidence-based practice in the ICU?
		What is the role of ICU telemedicine in protocol and guideline adherence?
		How can telemedicine be used in continuing education, including performance-based education based on quality improvement?
Outcome	Patient	What is the effect of ICU telemedicine on mortality, quality of life, and end-of-life care?
		What is the effect of ICU telemedicine on patient and family satisfaction?
		What is the effect of telemedicine on diagnostic accuracy and timeliness?
		In what ways does telemedicine either prevent or facilitate medical errors?
	Provider	What is the effect of ICU telemedicine on operational outcomes, such as length of stay, throughput, and readmission rates?
		What are the effects of telemedicine on the incidence, timeliness, and appropriateness of interhospital transfers?
	System	What is the cost-effectiveness of telemedicine?
		How do varying clinician and hospital reimbursement schemes affect telemedicine use and effectiveness?

emergency care (ie, CPR). Given the capacity for telemedicine to introduce redundant processes into health care, research is needed into the capacity of such redundancy to affect safety. Investigations of unintended consequences also are needed, including the potential for telemedicine to introduce medical errors, as might occur when there is ambiguity of responsibility in a redundant system.[38]

Finally, research is needed into outcomes from the health-system perspective, particularly the cost-effectiveness of ICU telemedicine. Such research should consist of formal cost-effectiveness analyses based on the recommendations of the US Panel on Cost-Effectiveness in Health and Medicine.[39] Cost analyses should take both the hospital and the societal perspectives and use an appropriate time horizon. These analyses also should account for all relevant cost centers, including hardware, software, staffing costs, opportunity costs, education costs both for launch and for maintenance, and audit and feedback costs. Additionally, research is needed into the role of different physician and hospital reimbursement models for ICU telemedicine, including financial incentives to encourage quality improvements without encouraging overuse or unnecessary expansion of unhelpful information technology.

When evaluating outcomes, working group participants stressed that whenever possible, research should address causation rather than just association. The difficulty in inferring the direct consequences of a complex health intervention is a common limitation of observational research but is particularly problematic in the before-and-after study designs that predominate in existing telemedicine evaluations. Future research should attempt to elucidate causality by using stronger study designs, including cluster randomized controlled trials and multicenter observational studies with control ICUs that do not have a telemedicine program. These studies should control for temporal-, patient-, organizational-, and system-level confounders in a way that minimizes bias due to changes in case mix or coincident interventions.

Conclusions

The use of ICU telemedicine is likely to expand in the coming years, and further technological innovations will continue to change the way we deliver critical care. Use of these innovations should not necessarily wait until definitive evidence of effectiveness exists yet neither should their adoption be uninformed by high-quality research. In this regard, it is essential

that expansion of telemedicine be accompanied by critical evaluation leading to a comprehensive evidence base.[40] The alternative is that the expansion be driven by individual and commercial biases and the technological imperative. For good or bad, ICU telemedicine can elicit a strong emotional response from ICU stakeholders, especially from those with a financial stake in its adoption or nonadoption. Recognizing and overcoming these biases are important challenges to future research. ICU telemedicine provides a critical opportunity to gain insight into the aspects of adult critical care delivery that affect outcomes. Understanding the mechanisms of care delivery that bring the most value is fundamental to advancing the field.

In the end, the most important research questions surround how we use telemedicine in the care of critically ill patients. The true value of ICU telemedicine lies not in whether the technology exists but in how it is applied, how well it is leveraged by ICU clinicians, and how it affects workflow and team integration. The most valuable research will uncover strategies to optimize the effectiveness of telemedicine in a way that is clear and understandable to clinicians and hospital administrators whose decisions are guided by this research. The development of the methodological framework recommended by this workshop will provide an essential foundation for this research. The resulting studies should provide insight into how to apply telemedicine in the most effective and cost-effective manner, in the highest impact clinical settings, and with minimal adverse consequences.

References

1. Perednia DA, Allen A. Telemedicine technology and clinical applications. *JAMA*. 1995;273(6):483-488.
2. Groves RH Jr, Holcomb BW Jr, Smith ML. Intensive care telemedicine: evaluating a model for proactive remote monitoring and intervention in the critical care setting. *Stud Health Technol Inform*. 2008;131:131-146.
3. Angus DC, Shorr AF, White A, Dremsizov TT, Schmitz RJ, Kelley MA; Committee on Manpower for Pulmonary and Critical Care Societies (COMPACCS). Critical care delivery in the United States: distribution of services and compliance with Leapfrog recommendations. *Crit Care Med*. 2006;34(4):1016-1024.
4. Angus DC, Kelley MA, Schmitz RJ, White A, Popovich J 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.
5. Yoo EJ, Dudley RA. Evaluating telemedicine in the ICU. *JAMA*. 2009;302(24):2705-2706.
6. 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.
7. 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.
8. Marcin JP, Nesbitt TS, Kallas HJ, Struve SN, Traugott CA, Dimand RJ. Use of telemedicine to provide pediatric critical care inpatient consultations to underserved rural Northern California. *J Pediatr*. 2004;144(3):375-380.
9. Zawada ET Jr, Kapaska D, Herr P, et al; Avera eICU Research Group. Prognostic outcomes after the initiation of an electronic telemedicine intensive care unit (eICU) in a rural health system. *S D Med*. 2006;59(9):391-393.
10. 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.
11. 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.
12. 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.
13. McCambridge M, Jones K, Paxton H, Baker K, Sussman EJ, Etchason J. Association of health information technology and teleintensivist coverage with decreased mortality and ventilator use in critically ill patients. *Arch Intern Med*. 2010; 170(7):648-653.
14. Grundy BL, Crawford P, Jones PK, et al. Telemedicine in critical care: an experiment in health care delivery. *JACEP*. 1977;6(10):439-444.
15. LaMonte MP, Bahouth MN, Hu P, et al. Telemedicine for acute stroke: triumphs and pitfalls. *Stroke*. 2003;34(3): 725-728.
16. Rogers FB, Ricci M, Caputo M, et al. The use of telemedicine for real-time video consultation between trauma center and community hospital in a rural setting improves early trauma care: preliminary results. *J Trauma*. 2001;51(6): 1037-1041.
17. Marcin JP, Schepps DE, Page KA, Struve SN, Nagrampa E, Dimand RJ. The use of telemedicine to provide pediatric critical care consultations to pediatric trauma patients admitted to a remote trauma intensive care unit: a preliminary report. *Pediatr Crit Care Med*. 2004;5(3):251-256.
18. Vespa PM, Miller C, Hu X, Nenov V, Buxey F, Martin NA. Intensive care unit robotic telepresence facilitates rapid physician response to unstable patients and decreased cost in neurointensive care. *Surg Neurol*. 2007;67(4):331-337.
19. Westbrook JI, Coiera EW, Brear M, et al. Impact of an ultrabroadband emergency department telemedicine system on the care of acutely ill patients and clinicians' work. *Med J Aust*. 2008;188(12):704-708.
20. LaMonte MP, Bahouth MN, Xiao Y, Hu P, Baquet CR, Mackenzie CF. Outcomes from a comprehensive stroke telemedicine program. *Telemed J E Health*. 2008;14(4): 339-344.
21. Meidl TM, Woller TW, Iglar AM, Brierton DG. Implementation of pharmacy services in a telemedicine intensive care unit. *Am J Health Syst Pharm*. 2008;65(15):1464-1469.
22. Forni A, Skehan N, Hartman CA, et al. Evaluation of the impact of a tele-ICU pharmacist on the management of sedation in critically ill mechanically ventilated patients. *Ann Pharmacother*. 2010;44(3):432-438.
23. Tang Z, Weavind L, Mazabob J, Thomas EJ, Chu-Weininger MY, Johnson TR. Workflow in intensive care unit remote monitoring: a time-and-motion study. *Crit Care Med*. 2007; 35(9):2057-2063.
24. Stafford TB, Myers MA, Young A, Foster JG, Huber JT. Working in an eICU unit: life in the box. *Crit Care Nurs Clin North Am*. 2008;20(4):441-450.
25. Berenson RA, Grossman JM, November EA. Does telemonitoring of patients—the eICU—improve intensive care? *Health Aff (Millwood)*. 2009;28(5):w937-w947.
26. Koepsell TD, Weiss NS. *Epidemiologic Methods: Studying the Occurrence of Illness*. New York, NY: Oxford University Press; 2003.
27. Craig P, Dieppe P, Macintyre S, Michie S, Nazareth I, Petticrew M. Developing and evaluating complex interventions: the new Medical Research Council guidance. *BMJ*. 2008; 337:a1655. http://www.bmj.com/content/337/bmj.a1655.full. Accessed March 15, 2011.
28. Fan E, Laupacis A, Pronovost PJ, Guyatt GH, Needham DM. How to use an article about quality improvement. *JAMA*. 2010;304(20):2279-2287.
29. Puskin DS, Brink LH, Mintzer CL, Wasem CJ. Joint federal initiative for creating a telemedicine evaluation framework. *Telemed J*. 1995;1(4):395-399.
30. Ferrer R, Artigas A, Levy MM, et al; Edusepsis Study Group. Improvement in process of care and outcome after a multicenter severe sepsis educational program in Spain. *JAMA*. 2008;299(19):2294-2303.
31. Pronovost P, Needham D, Berenholtz S, et al. An intervention to decrease catheter-related bloodstream infections in the ICU. *N Engl J Med*. 2006;355(26):2725-2732.
32. Donabedian A. The quality of medical care. *Science*. 1978; 200(4344):856-864.
33. Young LB, Chan PS, Cram P. Staff acceptance of tele-ICU coverage: a systematic review. *Chest*. 2011;139(2):279-288.
34. Chu-Weininger MY, Wueste L, Lucke JF, Weavind L, Mazabob J, Thomas EJ. The impact of a tele-ICU on provider attitudes about teamwork and safety climate. *Qual Saf Health Care*. 2010;19(6):1-5.
35. Hu PJ, Chau PYK, Sheng ORL, Tam KY. Examining the technology acceptance model using physician acceptance of telemedicine technology. *J Manage Inform Syst*. 1999; 16(2):91-112.
36. Dellinger RP, Levy MM, Carlet JM, et al; International Surviving Sepsis Campaign Guidelines Committee; American Association of Critical-Care Nurses; American College of

Chest Physicians; American College of Emergency Physicians; Canadian Critical Care Society; European Society of Clinical Microbiology and Infectious Diseases; European Society of Intensive Care Medicine; European Respiratory Society; International Sepsis Forum; Japanese Association for Acute Medicine; Japanese Society of Intensive Care Medicine; Society of Critical Care Medicine; Society of Hospital Medicine; Surgical Infection Society; World Federation of Societies of Intensive and Critical Care Medicine. Surviving Sepsis Campaign: international guidelines for management of severe sepsis and septic shock: 2008. *Crit Care Med*. 2008;36(1):296-327.

37. Kahn JM, Kramer AA, Rubenfeld GD. Transferring critically ill patients out of hospital improves the standardized mortality ratio: a simulation study. *Chest*. 2007;131(1):68-75.
38. Greenberg CC, Regenbogen SE, Studdert DM, et al. Patterns of communication breakdowns resulting in injury to surgical patients. *J Am Coll Surg*. 2007;204(4):533-540.
39. 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.
40. Merrell RC, Doarn CR. Where is the proof? *Telemed J E Health*. 2010;16(2):125-126.