

# Telemedicine Coverage of Intensive Care Units: A Narrative Review



Kelly C. Vranas<sup>1</sup>, Christopher G. Slatore<sup>1,2</sup>, and Meeta Prasad Kerlin<sup>3,4</sup>

<sup>1</sup>Division of Pulmonary and Critical Care Medicine, Department of Medicine, Oregon Health and Science University, Portland, Oregon; <sup>2</sup>Health Services Research and Development, VA Portland Health Care System, Portland, Oregon; and <sup>3</sup>Palliative and Acute Illness Research Center and <sup>4</sup>Division of Pulmonary, Allergy, and Critical Care Medicine, Department of Medicine, Perelman School of Medicine at the University of Pennsylvania, Philadelphia, Pennsylvania

ORCID IDs: 0000-0001-7450-3717 (K.C.V.); 0000-0002-3239-1443 (M.P.K.).

## Abstract

Telemedicine coverage of intensive care units is an organizational innovation that has been touted as a means to improve access to and quality of critical care. The purpose of this narrative review is to discuss the different organizational models of intensive care unit

telemedicine and factors that have influenced its adoption and to review the existing literature to consider whether it has lived up to its promise. We conclude by suggesting future directions to fill in some of the existing gaps in the literature.

**Keywords:** critical care; ICU administration; telemedicine

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Correspondence and requests for reprints should be addressed to Meeta Prasad Kerlin, M.D., M.S.C.E., 302 Blockley Hall, 423 Guardian Drive, Philadelphia, PA 19104. E-mail: prasadm@pennmedicine.upenn.edu.

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The intensive care unit (ICU) is traditionally defined as a dedicated area in the hospital where acute care services are provided to patients requiring invasive, life-sustaining therapies and who are at high risk of dying (1, 2). More than 5 million patients are admitted annually to ICUs in the United States, and nearly one in five Americans will die after using ICU services (2, 3). Critical care is both resource intensive and costly, consuming nearly 15% of all hospital costs in the United States, with total costs approaching 1% of the U.S. gross domestic product (4, 5). As a result, substantial efforts have been made in recent years to improve its overall quality, value, and efficiency.

Although it is traditionally defined by what happens in an ICU, modern critical care is less a technologic creation and more of an organizational innovation (6). Therefore, it stands to reason that improvements in ICU

quality and efficiency might be maximized through innovations in the reorganization of its care delivery system (6, 7). ICU telemedicine is defined as the provision of care to critically ill patients by healthcare professionals located remotely. It is a particularly appealing strategy because of its potential ability to improve access to trained intensivists, whose in-house presence is associated with lower mortality, shortened ICU length of stay (LOS), and lower costs for critically ill patients (8, 9). The demand for critical care has already and will further outpace the supply of intensivists in the setting of the aging U.S. population (10, 11); ICU telemedicine has been proposed as an intervention that may help alleviate this workforce crisis (12, 13). ICU telemedicine providers typically use electronic medical records combined with audiovisual technologies to assist bedside caregivers in patient care activities, including best practice

adherence, monitoring of clinical stability, and the creation and execution of care plans (14–16).

In this review, we describe the history of ICU telemedicine and its different models of implementation in the United States (as very few data on international adoption of ICU telemedicine exist), explore factors influencing its adoption, review the evidence regarding its effectiveness, discuss potential mechanisms for successful implementation, and propose directions for future research.

## The History and Organizational Models of ICU Telemedicine

ICU telemedicine was first reported in 1977. Via a two-way audiovisual link, an intensivist at a university hospital remotely conducted daily rounds and once-weekly

teaching conferences with staff of a small nonacademic ICU (17). Through their groundbreaking experience, the authors concluded that ICU telemedicine was feasible, though expensive; was generally acceptable to both patients and ICU staff; and had great potential to improve patient care, provide education, and facilitate the establishment of multihospital networks.

The next two decades saw a substantial improvement in telemedicine technologies, including communication strategies, patient monitoring systems, computerized data collection, and clinical decision support (18). In 1997, a team of investigators at an academic medical center conducted a feasibility study in which they used telemedicine to achieve 24-hour intensivist coverage of a 10-bed surgical ICU at an affiliate hospital over a 16-week period (19, 20). Associated with a marked reduction in severity-adjusted ICU and hospital mortality, ICU LOS, and hospital costs, the ICU telemedicine program was expanded across multiple ICUs in the same healthcare system using commercially available equipment. In a subsequent multisite roll-out, the ICU telemedicine intervention was again associated with significantly reduced hospital mortality (12.9% vs. 9.4%) and ICU LOS (4.35 d vs. 3.63 d) (20). These results ultimately led to the development of the predominant ICU telemedicine technology in the United States, broader commercialization of telecommunication technologies, and subsequent expansion of ICU telemedicine across the United States, from 16 hospitals in 2003 to 213 hospitals in 2010, with most of

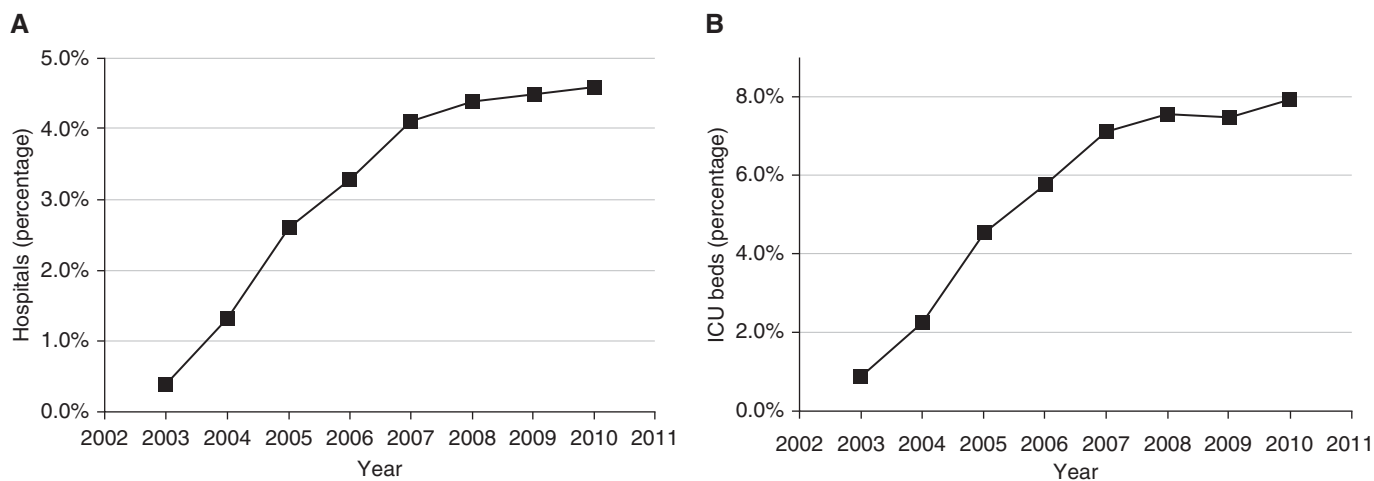
the growth occurring in the first 4 years of the expansion (14, 21, 22) (Figure 1).

Today, ICU telemedicine programs are more widespread, covering at least 15% of ICU beds in the United States (18, 21), but with considerable variation in how and where they have been implemented. For example, ICUs that use telemedicine are widely dispersed geographically and serve communities of all sizes, including both rural and urban settings. They are also located in hospitals that vary substantially in size, from as few as 25 to more than 1,000 licensed beds (23). Despite this variability, certain adoption patterns have emerged (23). Compared with nonadopting hospitals, those with ICU telemedicine programs are more likely to be large, nonprofit, teaching hospitals located in urban settings and with greater access to resources, including major technologies (21).

The most common model is the centralized telemedicine unit, which uses a hub-and-spoke model from which critical care services originate (22, 24). The hub (or center) is the remote site from which a multidisciplinary team (including variable combinations of intensivists, nurses, advanced practitioners, pharmacists, respiratory therapists, and administrative staff) provides off-site monitoring for critically ill patients. Alternatively, the decentralized model uses a reverse hub-and-spoke model, in which there is no central monitoring facility. In this model, computers equipped with audiovisual technology are also located at sites of patient care, but the remote monitoring occurs from sites of convenience for individual remote

care providers, such as physician offices or homes (24). Some ICU telemedicine programs have a logistic center that manages patient flow (including ICU admissions and intra- or interhospital transfers) within a hospital or health system (25). Many telemedicine units provide benchmarking data to monitored ICUs, including rates of adherence to evidence-based practices, patient outcomes data, and professional service revenue data; however, how these types of data are reported or used is not well described.

The intensity of interaction between ICU telemedicine program and bedside providers varies widely across three primary domains: time, reactivity, and scope. For example, the ICU telemedicine team may provide services intermittently or in a continuous fashion up to 24 hours per day. ICU telemedicine programs may implement a reactive model, in which telemedicine providers respond to automated alerts for worrisome trends that may not yet be recognized by the bedside providers or to requests for involvement from bedside providers. Such requests may be based on prespecified criteria, such as new admissions, the need for certain therapies indicative of critical illness (such as vasopressors or mechanical ventilation), emergency situations, or questions concerning patient care (22, 26). In contrast, a proactive model typically involves the continuous remote surveillance of patients, including the methodical review of patient data and best-practice adherence (e.g., lung-protective ventilation for patients with acute



**Figure 1.** Growth of intensive care unit (ICU) telemedicine over time, expressed as (A) percentages of all U.S. hospitals using this service, and (B) percentages of ICU beds covered. Reprinted by permission from Reference 21.

respiratory distress syndrome) (22). Scheduled (i.e., preemptive) care models also exist, in which virtual visits by the remote provider occur at defined times rather than in response to prompting from the bedside team (24). Importantly, these models of reactivity are not mutually exclusive. Scope of involvement by the ICU telemedicine team also varies substantially, ranging from minimal discretion only (e.g., the ICU telemedicine team only intervenes for life-threatening situations) up to full discretion (e.g., the telemedicine team has full prescribing authority ranging from placing routine orders to changing treatment plans) (27). In this way, bedside providers can adjust the intensity of involvement by the ICU telemedicine program across these domains depending on the local culture and resources available.

The ICU telemedicine team typically expands the number of clinicians involved in patient care by adding a number of remote providers to the bedside provider team (28). However, there are no guidelines to establish the optimal “dose” of remote providers or the ideal composition of the multidisciplinary team. ICU telemedicine teams are staffed with, on average, one nurse per 30 to 35 ICU beds and one intensivist per 100 to 130 patients (28). In one survey, ICU telemedicine centers were staffed an average of 16.5 hours per weekday. Weekday staffing included a median of three nurses, with a range of 1 to 12, and one intensivist, with a range of 1 to 3. Staffing tended to increase with the number of beds being evaluated by the ICU telemedicine program (23).

## Factors Influencing ICU Telemedicine Adoption

The rapid expansion of ICU telemedicine in the early 2000s was based on its potential to improve patient outcomes and quality of care (14). Patient safety and increased access to an intensivist workforce that falls short of demand are often cited as primary motivations for adoption (2, 10, 22, 28, 29). Other proposed benefits of ICU telemedicine include the ability to recognize worrisome vital signs or laboratory trends more quickly than bedside providers would alone (28, 30, 31) and to target care processes associated with better outcomes, including more rapid initiation of life-sustaining therapies and shorter response times to alarms (16, 22, 32–34). ICU

telemedicine programs may also aid in the identification of patients appropriate for transfer to higher levels of care; alternatively, the supplemental care provided by the remote clinicians may enable patients to remain in their community facilities who would have otherwise been transferred (35). In addition, ICU telemedicine can add to the quality improvement infrastructure within hospitals. Through the ability to capture and analyze large amounts of data, ICU telemedicine programs can provide benchmarking reports to individual hospitals about their overall performance over time and compared with other similar facilities. Finally, some hospitals have viewed ICU telemedicine as a way to build relationships with smaller hospitals, support the development of regional care delivery systems, increase revenue by selling their ICU telemedicine services to unaffiliated hospitals, enable hospitals to provide high-risk procedures to patients with complicated medical histories, or distinguish themselves in competitive markets (28, 36).

Despite its initial rapid expansion, the adoption of ICU telemedicine programs appears to have slowed down over recent years, possibly related to the recent recession across the United States that led to reduced investment in healthcare infrastructure (21). Indeed, cost is a major barrier to adoption (28). A 2013 systematic review estimated the cost to implement an ICU telemedicine program for 1 year was between \$50,000 and \$123,000 (in 2011 U.S. dollars) per monitored ICU bed, with subsequent operating costs of up to \$3 million annually (15, 37, 38). Few studies have assessed the financial return on investment of ICU telemedicine, and those that have reported significant cost benefits often contain limited data on actual financial savings and rarely describe their accounting methods (20, 37, 39). A recent study using an activity-based micro-accounting method at a single academic institution found that implementation of ICU telemedicine led to favorable clinical outcomes and financial benefits that exceeded program capital and operating costs through increased case volume, higher case revenue relative to direct costs, and shorter LOS (40). In contrast, several other studies have shown that ICU telemedicine is associated with higher net costs (41, 42).

ICU telemedicine also faces legal and regulatory challenges. Some states require providers to have a special license to deliver

telemedicine services from out of state (36). States also vary in their policies regulating reimbursement for ICU telemedicine services. Because patients may never know that they have been seen by a remote physician, controversy exists as to whether ICU telemedicine services function as a surrogate for in-person care or as an enhanced level of care that augments in-person care (43, 44).

## Has ICU Telemedicine Lived up to Its Promise?

There are persistent questions about the benefit of ICU telemedicine for multiple reasons (45). First, the paucity of high-quality evidence prevents strong conclusions about its overall effectiveness. Most existing studies are pre-post studies without concurrent controls (46) and without consistent measurement, reporting, and adjustment for patient severity (47). Furthermore, many studies lack details about how ICU telemedicine was implemented. Because it is such a complex intervention, program structures and local buy-in can vary greatly, likely substantially affecting its overall effectiveness.

With these caveats in mind, a review of the existing literature demonstrates mixed effects of ICU telemedicine on patient outcomes, as summarized in Table 1. Most of the early before-after studies demonstrated significant improvement in patient outcomes associated with implementation of ICU telemedicine (19, 20, 48–51), although the interventions were notably different across these studies in several ways, including (but not limited to) the composition of the ICU telemedicine team, the surveillance models and frequency, and the organization of the target ICUs (Table 1). These positive findings were reinforced by a large study in a single academic center published in 2011 (16). Notably, in this study, remote clinicians worked synergistically with bedside providers to enforce daily goals, respond to bedside alarms, and review adherence to evidence-based practices. Authors reported a significant decrease in risk-adjusted hospital mortality after implementation of the ICU telemedicine program (adjusted odds ratio, 0.40). ICU admission postintervention was also associated with significantly higher rates of best clinical practice adherence, lower rates of ICU-acquired complications, and shorter

**Table 1.** Summary of comparative studies evaluating the effectiveness of intensive care unit telemedicine programs

<b>Study</b>	<b>Summary of Study Design: No. ICUs/Hospitals; No. of Patients in Control/ Telemedicine Groups</b>	<b>Characteristics of ICU Telemedicine Program: Model Timing Reactivity Scope Team Composition</b>	<b>Characteristics of Target ICU: ICU Type(s) Staffing Model ICU Teaching Status</b>	<b>Major Findings</b>
Rosenfeld <i>et al.</i> , 2000 (19)	Retrospective observational study with two historical control groups: 1 ICU/1 hospital; 427/201	Decentralized Continuous Proactive and reactive Full discretion 1 Intensivist	SICU Open Teaching	Reduced ICU mortality Reduced hospital mortality Reduced incidence of ICU complications Reduced ICU LOS Reduced costs
Breslow <i>et al.</i> , 2004 (20)	Retrospective observational study with historical control group: 2 ICUs/1 hospital; 1,396/744	Centralized Intermittent (19 h/d) Proactive and reactive Variable depending on bedside attending preference 1 Intensivist, 1 RN and 1 clerical staff	MICU, SICU Open Mixed teaching and nonteaching patients	Reduced hospital mortality Reduced ICU LOS Lower variable costs per case
Thomas <i>et al.</i> , 2009 (27)	Pre-post observational study: 6 ICUs/5 hospitals; 2,034/2,108	Centralized Continuous Proactive and reactive Variable depending on bedside attending preference 2 Intensivists (19 h/d on weekdays), 4 RNs, and 2 clerical staff	MICU, SICU, MSICU Variable depending on site Variable depending on site	No difference in hospital or ICU mortality overall, but reduced hospital and ICU mortality among patients with higher severity of illness No difference in hospital or ICU LOS
Zawada <i>et al.</i> , 2009 (48)	Pre-post observational study: 4 ICUs/4 hospitals; 188/2,445	Centralized Continuous Proactive and reactive Minimal discretion 1 physician (not always intensivist) 20 h/d; 1 RN and 1 clerical staff 24 h/d	MSICU Open Nonteaching	Medium-sized regional hospitals: Could not evaluate severity-adjusted mortality, reduced ICU LOS. Tertiary hospital: Reduced observed-to-predicted ICU and hospital mortality, reduced observed-to-predicted ICU and hospital LOS
McCambridge <i>et al.</i> , 2010 (49)	Pre-post observational study: 3 ICUs/1 hospital; 954/959	Centralized Intermittent (7 P.M. to 7 A.M.) Proactive and reactive Full discretion 1 Intensivist and 1 RN	Not specified Closed Nonteaching	Reduced ICU mortality Reduced use of mechanical ventilation No difference in ICU or hospital LOS
Morrison <i>et al.</i> , 2010 (42)	Retrospective observational study with historical control group, early ICU telemedicine group, and late (well-established) ICU telemedicine group: 4 ICUs/2 hospitals; 1,371/2,717	Not specified Not specified Proactive Variable depending on bedside attending preference Not specified	MICU, SICU, CICU, MSICU Open Teaching (MICU, SICU, CICU), nonteaching (MSCIU)	No difference in ICU or hospital mortality No difference in ICU or hospital LOS No difference in costs

(Continued)

Table 1. (Continued)

Study	Summary of Study Design: No. ICUs/Hospitals; No. of Patients in Control/ Telemedicine Groups	Characteristics of ICU Telemedicine Program: Model Timing Reactivity Scope Team Composition	Characteristics of Target ICU: ICU Type(s) Staffing Model ICU Teaching Status	Major Findings
Lilly <i>et al.</i> , 2011 (16)	Prospective observational study with stepped-wedge implementation: 7 ICUs/2 hospitals; 1,529/4,761	Centralized Continuous Proactive and reactive Full discretion Intensivist present; rest of team not specified	MICU, SICU, CICU Closed Teaching hospitals; individual ICU staffing not specified	Reduced hospital mortality Reduced hospital LOS Higher rates of best practice adherence Reduced ICU complications
Kohl <i>et al.</i> , 2012 (51)	Pre-post observational study in surgical ICU with medical ICU as temporal control: 2 ICUs/1 hospital; 466/1,784	Centralized Continuous Proactive and reactive Full discretion 2 RNs during day (7 A.M. to 7 P.M.), and 1 intensivist and 1 RN during night (7 P.M. to 7 A.M.)	MICU (control), SICU (intervention) MICU closed; SICU open Teaching	Reduced ICU and hospital mortality Reduced ICU LOS
Willmitch <i>et al.</i> , 2012 (50)	Pre-post observational study with one preimplementation period compared to three consecutive postimplementation periods 10 ICUs/5 hospitals; 6,504/18,152	Centralized Variable depending on site Not specified Variable depending on attending preferences 1 intensivist, 3 RNs, 1 clerical staff	Not specified Variable depending on site Not specified	Reduced hospital mortality Reduced hospital LOS Reduced ICU LOS
Lilly <i>et al.</i> , 2012 and 2014 (23, 30)	Multicenter retrospective cohort study: 56 ICUs/32 hospitals; 11,558/107,432	Variable depending on site Variable depending on site Variable depending on site Variable depending on site	Variable depending on site Variable depending on site Variable depending on site Variable depending on site	Reduced ICU mortality Reduced hospital mortality Reduced ICU LOS Reduced hospital LOS
Nassar <i>et al.</i> , 2014 (54)	Retrospective observational study including pre-post analysis within ICUs implementing telemedicine programs, in addition to concurrent control ICUs without telemedicine: 8 telemedicine ICUs with 8 matched control ICUs/7 hospitals; 3,584/3,355	Centralized Intermittent (21 h/d) Variable depending on the site Variable depending on the site 1 intensivist and 2 RNs	MICU, SICU, MSICU Variable depending on site Variable depending on site	No difference in ICU mortality No difference in hospital mortality No difference in 30-d mortality No difference in LOS
Kahn <i>et al.</i> , 2016 (52)	Multicenter retrospective case-control study, matching adopting hospitals (cases) to up to 3 nonadopting hospitals (controls): No. ICUs not specified/132 case hospitals with 389 control hospitals; 830,927/292,636	Centralized Not specified Not specified Not specified Not specified	Not specified Not specified Variable depending on site	Reduced 90-d mortality Most effective in large urban hospitals

Definition of abbreviations: CICU = cardiac intensive care unit; ICU = intensive care unit; LOS = length of stay; MICU = medical intensive care unit; MSICU = medical surgical intensive care unit; RN = registered nurse; SICU = surgical intensive care unit.



hospital LOS (16). A subsequent large, multicenter observational study evaluated the relationship between individual processes of care that varied among ICU telemedicine interventions and the outcomes of ICU and hospital mortality and ICU and hospital LOS. The authors found that four individual components of the interventions were associated with better outcomes, including prompt remote intensivist case review, improved adherence to evidence-based practices, reduced response times to alarms, and the real-time use of performance measures (22, 30). By identifying individual domains associated with improved outcomes post-ICU telemedicine implementation, authors offered plausible mechanisms for the potential effectiveness of this intervention (29). Finally, a recent large national study evaluating the effectiveness of ICU telemedicine programs with concurrent controls showed a small relative mortality reduction with wide variation in ICU telemedicine effect across adopting hospitals, although this study used an administrative database that lacked detailed clinical risk adjustment (52).

However, multiple other observational studies with similar limitations did not find any association of ICU telemedicine with improved patient outcomes (42, 53, 54). Specifically, one study in multiple ICUs across a large U.S. healthcare system evaluated the association of ICU telemedicine with patient outcomes. Of note, ICUs in this study incorporated varying degrees of involvement of the remote ICU telemedicine team and also used a variety of open and closed staffing models (49, 53). The authors reported no difference in severity-adjusted mortality or LOS after intervention. However, they did report decreased mortality for the most severely ill patients after ICU telemedicine implementation, which is consistent with findings from several other studies (41, 53, 55, 56). In another study conducted within the Veterans Affairs Healthcare System using a methodologically rigorous design across seven hospitals with matched controls, authors did not find an association of ICU telemedicine with patient outcomes but noted that their study cohort had an extremely low ICU mortality rate of 2.9%, making it difficult to detect a statistically significant reduction in mortality (54). More recently, one study evaluated whether implementation of an ICU telemedicine program across a regional healthcare system was associated with reduced

interhospital transfers (25). Somewhat unexpectedly, they found that interhospital transfers were significantly increased after implementation of the ICU telemedicine intervention, without associated changes in mortality or LOS. This finding was driven primarily by transfers from less specialized to more specialized ICUs and was not readily explained by increased severity of illness (25).

Several systematic reviews and meta-analyses based on these mostly uncontrolled, before–after observational studies concluded that significant associations of ICU telemedicine with reduced ICU mortality and LOS exist, with variable conclusions for hospital mortality and LOS (46, 57). Overall, these data suggest that ICU telemedicine may improve patient outcomes, but likely only when applied in the appropriate setting (29). Unfortunately, the specific characteristics of the target hospital, ICU, and ICU telemedicine unit necessary to optimize the intervention’s effectiveness remain largely undefined. It is also unclear which component of the intervention (e.g., additional providers vs. effects on processes measures vs. the technology itself) may provide greater benefit to patients.

Finally, the cost effectiveness of ICU telemedicine remains uncertain. Multiple studies have demonstrated this intervention to be more cost effective when directed toward the care of sicker patients (41, 56, 58). For example, a simulation analysis on the basis of previously published literature and using hypothetical ICU patients found that the optimal cost effectiveness of ICU telemedicine was achieved when applied to the 30% to 40% highest-risk patients among all ICU patients in urban tertiary hospitals (56). On the other hand, a 2017 study found that implementation of an ICU telemedicine program (including a logistic center that helped manage ICU admissions and discharges) was associated with lower LOS, which translated into greater case volume. This finding, in combination with increased per-case revenue attributed to a structured documentation system that more efficiently captured clinical information, improved financial performance within a single academic medical center (38).

Another recent study of Emory University Critical Care Center’s innovative ICU telemedicine and advanced practice provider training program demonstrated a significant reduction in average Medicare spending per care episode associated with the program’s implementation. These

findings were primarily driven by reduced readmissions within 60 days and substitution of home health care for institutional post-acute care for Medicare fee-for-service beneficiaries (59). Despite this, authors noted that sustaining the complex intervention was challenging, because ICU admissions covered by the remote ICU telemedicine providers were reimbursed at the same rate as standard ICU stays despite the added cost of the program (59). Ultimately, the cost effectiveness of ICU telemedicine likely varies between facilities depending on their individual case mix and volume, reimbursement strategy, staffing patterns, presence of existing electronic medical record, and number of beds over which the costs are depreciated (37, 59, 60). For these reasons, the most pressing questions regarding ICU telemedicine intervention at this point is not only whether telemedicine works, but also how, where, and which components of the intervention work best depending on the unique local culture and resources available in a given setting (13).

### How and Where Might ICU Telemedicine Be Successfully Implemented?

Certain themes have emerged in the literature over the last two decades that provide some guidance as to how and where ICU telemedicine might be most effective. First, sicker patients may benefit more from ICU telemedicine intervention than less-sick patients (27, 41, 55, 56). Indeed, if patients are not actually critically ill, then having an intensivist involved in their care may not be cost effective or even beneficial (61). Second, although it was originally conceived as a way to expand intensivists’ reach and availability to rural areas, ICU telemedicine may be particularly effective in large urban hospitals (21, 52). ICU capacity strain—when demand on an ICU’s resources exceeds availability—may be the mechanism for this finding (62). Because hospitals located in urban centers are often tertiary care centers with higher daily census and acuity of illness, they may experience greater ICU capacity strain, which has been associated with increased mortality (63). By increasing the number of available care providers, albeit remotely, ICU telemedicine may be one tool that enables ICUs to be more elastic than others during times of high strain, helping to ensure that care remains timely, comprehensive, and accurate (62, 64).

In addition, the impact of ICU telemedicine on patient outcomes varies greatly depending on where and how the intervention is applied (45). Table 2 provides some organizational strategies that may maximize the potential benefit of ICU telemedicine. Important factors to consider include the autonomy assigned to the ICU telemedicine team and the degree to which the technology is embraced by bedside clinicians. Studies in which these aspects were limited did not find an association between ICU telemedicine and patient outcomes (27, 54). However, studies in which the remote team was allowed full discretion in the care for all patients showed significant associations with improved mortality and LOS with the intervention (16, 30, 51). Identifying ways to improve collaboration and integration between the ICU remote team and the bedside providers is important for the effective implementation of ICU telemedicine programs.

A recent qualitative study of staff acceptance after ICU telemedicine implementation found that receipt of training about the technology, staff knowledge about when and how to use it, and perceived need for the program emerged as important themes influencing the acceptance of ICU telemedicine (65). Including bedside nurses as part of the off-site team is another approach to facilitate local acceptance of the ICU telemedicine intervention. Improved integration between the remote and local teams may also be greater when standards for sign-out, collaborative rounding models, and agreement on standard best practice approaches are developed jointly (66). This type of care model helps to encourage trust in the ICU telemedicine team, which in turn may allow them greater autonomy in the direct care of patients and translate into better outcomes. In addition, the use of a direct intervention with timely notification strategy by the remote ICU telemedicine team, rather than a passive monitor and notify approach, has been associated with improved outcomes (67).

Finally, ICU telemedicine programs may be more effective when they are used as tools for population management and are intentionally linked to specific quality-improvement initiatives and care processes (16, 29). For example, ICU telemedicine has been associated with better adherence to evidence-based practices, such as stress ulcer and venous thromboembolism prophylaxis, and lower rates of preventable complications (16, 30, 68, 69). Beyond these traditional approaches to quality improvement, other potentially important care processes associated with ICU telemedicine include the review of daily goal sheets to ensure implementation of care plans, and off-hours, off-site case review by intensivists (16). These care processes may be important contributors to the positive association of ICU telemedicine with patient outcomes observed in multiple studies (16, 30). Indeed, ICU telemedicine's greatest effectiveness may actually lie in its ability to ensure the consistent implementation of care plans and ICU best practices that have been proven to save lives, rather than in monitoring patients for clinical deterioration (14).

### Future Directions

ICU telemedicine is a promising mechanism to improve outcomes for critically ill patients. More insight into why some ICU telemedicine programs are effective and others are less successful is of utmost importance and requires a deeper understanding of how to maximize the value of these additional resources. Additional pre-post observational studies will not be helpful in answering these questions. Rather, future studies should be guided by frameworks of implementation science to allow for their results to be interpreted through the lens of relevance, generalizability, and applicability across health systems (70–72). Such an approach can enable a better understanding of ICU telemedicine's influence on the organization

and structure of the local ICUs and how organizational readiness for telemedicine before implementation may impact its effectiveness (14). For example, using a standardized approach to assess the preimplementation ICU environment is a key first step in efforts to understand the environmental and cultural factors that may influence the program's success and to allow valid comparisons across centers and sites (14). Mixed-methods research using both qualitative and quantitative approaches will also be necessary to better understand the crucial issue of context when studying if, how, when, and where ICU telemedicine is most effective (45). Finally, more research is needed into the optimal organizational structure of ICU telemedicine programs and staffing models, such as the optimal ratio of off-site providers to patients, and the core competencies required of the personnel staffing the ICU telemedicine units (14, 73).

### Conclusions

ICU telemedicine represents an organizational innovation that has the potential to improve access to and quality of critical care. However, its effectiveness is not necessarily assured and likely depends on the characteristics of the environment where it is deployed and the degree of collaboration between remote providers and bedside clinicians. It is crucial to recognize the wide range of implementation strategies for ICU telemedicine when interpreting existing evidence about its effects on the quality and efficiency of critical care. It is also important to account for local culture and resources when deciding whether to implement the intervention in a particular healthcare system. Although several decades of research have suggested many areas of potential benefit, we still lack understanding about how best to apply and leverage this technology to maximize its value and effectiveness. Future research using mixed-methods approaches and validated models for evaluating public health interventions will be essential to understand how, when, and whether ICU telemedicine should be implemented. ■

**Table 2.** Strategies to maximize potential benefit of intensive care unit telemedicine

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Ensure adequate autonomy of intensive care unit telemedicine team
Build integrated teams between remote providers and bedside clinicians
Promote active comanagement with direct intervention by telemedicine team
Develop telemedicine-based protocols for care processes and quality improvement
Incorporate internal benchmarking practices led by telemedicine team

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