



Telemedicine in the ICU: clinical outcomes, economic aspects, and trainee education

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Purpose of review

The evidence base for telemedicine in the ICU (tele-ICU) is rapidly expanding. The last 2 years have seen important additions to our understanding of *when*, *where*, and *how* telemedicine in the ICU adds value.

Recent findings

Recent publications and a recent meta-analysis confirm that tele-ICU improves core clinical outcomes for ICU patients. Recent evidence further demonstrates that comprehensive tele-ICU programs have the potential to quickly recuperate their implementation and operational costs and significantly increase case volumes and direct contribution margins particularly if additional logistics and care standardization functions are embedded to optimize ICU bed utilization and reduce complications. Even though the adoption of tele-ICU is increasing and the vast majority of today's medical graduates will regularly use some form of telemedicine and/or tele-ICU, telemedicine modules have not consistently found their way into educational curricula yet. Tele-ICU can be used very effectively to standardize supervision of medical trainees in bedside procedures or point-of-care ultrasound exams, especially during off-hours. Lastly, tele-ICUs routinely generate rich operational data, as well as risk-adjusted acuity and outcome data across the spectrum of critically ill patients, which can be utilized to support important clinical research and quality improvement projects.

Summary

The value of tele-ICU to improve patient outcomes, optimize ICU bed utilization, increase financial performance and enhance educational opportunities for the next generation of providers has become more evident and differentiated in the last 2 years.

Keywords

electronic ICU, tele-ICU, telemedicine

INTRODUCTION

A recent provocative read by veteran European intensivists Vincent, Slutsky and Gattinoni speculates what a critical care experience might look like in 2050. The authors envision that remote interactions and videoconferencing with doctors through telemedicine elements will become the new norm [1]. In another recent editorial, Vincent and Creteur [2] summarize in 10 points how hospitals of tomorrow will be different. One of the 10 points is titled 'Telemedicine will be everywhere.' Overall, reading through the various prognostications on the future role of telemedicine and actively participating in its expansion in our institution frequently reminds us of the evolution of information technology in the healthcare sector over the last 50–60 years: Following Roger's model of diffusion of innovation, initial niche applications for an exotic, novel, and expensive technology were undertaken only by innovators in the 1950s and 1960s. Later, then cautiously

broader acceptance was seen by early adopters in the 1970s, followed by the adoption by the early and late majorities of providers in the 1980s and 1990s, to the point where in 2018 information technology has permeated almost every aspect of today's healthcare and dominates daily workflows in care delivery. Imagine a similar change with telemedicine as the next logical chapter.

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KEY POINTS

- Tele-ICU increases access to expert intensivists and thereby bridges the worsening intensivist shortage.
- Tele-ICU improves patient safety, mortality and length of stay. This effect is enhanced by continuous and proactive monitoring over episodic involvement, frequent performance reviews as well as close integration of the tele-ICU team with existing bedside team structures.
- Tele-ICU with added logistics functions has the potential to optimize ICU bed utilization and enhance financial performance through increased case volume and standardization of care.
- Administrative buy-in, implementation and operation strategies surrounding change management and supportive and collaborative organizational structures significantly shape the success of tele-ICU operations.
- Tele-ICUs generate high-quality operational, physiologic and outcomes datasets for clinical research and quality improvement.

This review will focus on telemedicine interventions in critical care. For a more global discussion on the clinical spectrum of telehealth applications, please see the recent excellent review in *NEJM* [3¹¹].

DRIVERS OF TELE-ICU SOLUTIONS

Telemedicine in the ICU was born out of necessity to bridge a supply and demand gap for critical care providers of all levels. Factors that affect this critical care provider shortage are the ‘perfect storm’ of an aging population with increasing disproportionate ICU use needs, a fixed supply of new critical care providers, increasing exits and/or retirements and a geographical maldistribution of active intensivists [4¹²,5].

Timothy Buchman, the Editor-in-Chief of *Critical Care Medicine* recently published an article, which summarizes these factors and then goes on to describe the Emory University approach to bridging the provider gap through the use of innovative solutions. In addition to employing telemedicine solutions, his institution is at the forefront of training and deploying acute care nurse practitioners. This care delivery model is associated with similar outcomes compared with resident-driven care [6]. Additionally, their approach provides supervision through tele-ICU intensivist providers, creating a synergistic combination of solutions. Their most recent solution attempts to ameliorate the negative effects of nighttime intensivist work (which both bedside and electronic ICU providers are equally at

risk for) by taking advantage of differences in global time zones. Using the simple fact that it is daytime on the other side of the globe when it is nighttime in the United States, Emory has devised a system to provide US nighttime tele-ICU monitoring and intensivist coverage through a daytime center in Sydney, Australia (Turning Night into Day Program) using Emory intensivists [4¹²]. Other areas in Medicine like Radiology (tele-Radiology) as well as other tele-ICU operations have for some time been taking advantage of this ‘time-zone’ solution.

Tele-ICU may have been born out of necessity to simply bridge the provider gap, but in ‘growing up’ it ‘discovered’ other valuable abilities in the process. With the move to value-based care and ever decreasing hospital-operating margins, the pressure to define the value of telemedicine in the ICU is increasing as well. Value is defined as Quality divided by Cost or ‘Outcome Achieved per Dollar Spent’ [7]. ‘Quality’ strives for positives like clinical outcomes, patient/provider satisfaction, and enhanced postgraduate medical education. ‘Cost’ summarizes complex metrics that address resource utilization of ICU beds, providers, hospital throughput/capacity management and reduction of complications through standardization of care. The value equation ‘Value = Quality/Cost’ illustrates the overlap between clinical outcomes and economic metrics, which are both addressed successively below.

The evidence base for tele-ICU has rapidly expanded becoming more differentiated in the last decade. In particular, the last 2 years have seen interesting added evidence on clinical outcomes and economic benefits. Overall, we have evolved from the question as to *whether* telemedicine in the ICU adds value to the more differentiated view on *when, where and how*, that is, through which aspects of the multifactorial intervention and through which driving mechanisms value is added.

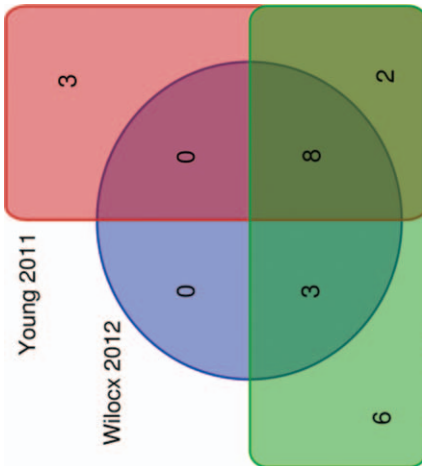
CLINICAL OUTCOMES OF TELE-ICU

Three systematic reviews and meta-analyses have been published assessing the effect of tele-ICU implementation on the core clinical outcomes of ICU and hospital mortality and length of stay (LOS). The most recent systematic review and meta-analysis was published just last year. It showed reduction of ICU and hospital mortality and ICU LOS, but not hospital LOS [8¹³].

We discussed the two previously published meta-analyses [9,10] in an editorial in 2016 [5].

Table 1 summarizes the findings of all three meta-analyses on the main outcome measures and details the number of studies shared between the three meta-analyses, which helps to explain the

Table 1. Recent meta-analyses on the effect of tele-ICU interventions on ICU and hospital mortality and length of stay

Publication year	Number of included studies	ICU mortality	Hospital mortality	ICU LOS	Hospital LOS	Venn diagram of included studies
Young [10]	13	Pooled OR 0.8 (CI 0.66–0.97, P=0.02)	Pooled OR 0.82 (CI 0.65–1.03, P=0.08)	Mean reduction –1.26 days (CI –2.21 to –0.30, P=0.01)	Mean reduction –0.64 days (CI –1.52 to 0.25, P=0.16)	
Wilcox [9]	11	Risk ratio 0.79 (CI 0.65–0.96)	Risk ratio 0.83 (CI 0.73–0.94)	Reduction of 0.62 days (CI –1.21 to –0.04 days)	Reduction of 1.26 days (CI –2.49 to –0.03 days)	
Chen [8***]	19	Risk ratio 0.83 (CI 0.72–0.96)	Risk ratio 0.74 (CI 0.58–0.96)	Reduction of 0.63 days (CI –1.09 to –0.17 days)	Reduction of 0.27 days (CI –1.14 to 0.59 days)	

The Venn diagram shows the numbers of shared versus unique studies between the three meta-analyses. CI, confidence interval; LOS, length of stay; OR, odds ratio.

differences in their findings (see the Venn diagram in the right column of Table 1). The constellation of more consistently confirmed ICU mortality and LOS reduction and less consistently confirmed effects on hospital mortality and LOS through tele-ICU implementation seems intuitive to us and mirrors our own experience (in preparation for publication), as a multitude of nontele-ICU-related additional factors are involved in determining hospital-based outcomes.

Kahn *et al.* [11[■]] in 2016 used a different combined data set of Medicare claims data linked to a national survey identifying hospitals adopting ICU telemedicine to confirm a positive effect of tele-ICU adoption on ICU mortality.

HOW DOES TELE-ICU ADD VALUE?

Subgroup analyses through meta-analyses as well as independent studies have contributed additional understanding to the question of *how* tele-ICUs convey their value.

The degree of integration of clinical information and monitoring as well as the clinical care teams clearly matters. Continuous monitoring with active alarms and alerts is more beneficial than episodic consultations only without continuous data feeds or alerting mechanisms [12].

Similarly, tele-ICU setups fostering integration and close collaboration with the bedside teams and giving the tele-ICU team authority to intervene and actively participate in patient care strengthens the outcomes improvement seen with tele-ICU implementation [9,12].

DOES THE CLINICAL VALUE OF TELE-ICU ALSO CARRY OVER INTO NON-ICU SETTINGS?

A recent publication found telemedicine interventions in the progressive care unit setting (TPCU) to be associated with similar mortality and LOS improvements to tele-ICU interventions [13].

Telemedicine may also add value when taking the ICU beyond its borders for the evaluation and management of decompensating general ward patients [rapid response teams (RRT)] [14].

CONTEXTUAL WORKLOAD

Unlike many other areas in medicine with fairly steady workloads, critical care environments inherently are very susceptible to large contextual workload fluctuations, and therefore varying stress levels. Using tele-ICU services specifically to alleviate contextual workload increases and surges in intensivist cognitive demand, in particular is a very attractive

concept for added value. A recent study found benefit in a tele-ICU service to alleviate postoperative Post Anesthesia Care Unit (PACU) surges in a large volume PACU-Surgical Intensive Care Unit (SICU) environment [15].

HANDOFFS

Another area of special interest to anesthesiologists is the operating room to ICU handoff. A recent study has shown potential to use videoconferencing participation and oversight as a standardization and quality improvement tool [16].

WHERE IS THE EVIDENCE FOR TELE-ICU VALUE ORIGINATING FROM?

The majority of evidence-based literature on telemedicine in the ICU originated in the United States. Use of tele-ICU is expanding from the USA to other parts of the world including London, UK and Tokyo, Japan as well as to Australia, where geographical variations in access to critical care expertise and distances for inter-facility transports to centers of excellence constitute accentuated challenges when compared with the United States. A recent publication from Australia provides a first assessment of the magnitude of benefit of tele-ICU approaches in this very large and inhomogeneously populated country [17].

ADULT VERSUS PEDIATRIC CRITICAL CARE

The scope of adoption and expansion of tele-ICU has been much larger in adult mixed and subspecialty ICU settings compared with pediatric and neonatal ICU settings. The driving forces for innovative solutions to staffing shortages are similar between adult and pediatric critical care. Expansion of telemedicine solutions in pediatrics is, therefore, to be expected to accelerate in the future. Nadar *et al.* [18] summarize the existing evidence base in pediatric acute care telemedicine, which overall lags behind but mirrors the evidence in the adult literature. Adult and pediatric/neonatal critical care providers train through different pathways, which makes cross-coverage of tele-ICU services across the age spectrum of critical care impossible unless the patient volume warrants deployment of both adult and pediatric critical care providers simultaneously. From the technical standpoint, differences in physiologic parameters like vital signs and laboratory values result in different acuity-scoring models and different alarm and alert parameters. As a result of these differences, adult and pediatric tele-ICU applications are, therefore, destined to coevolve.

ECONOMIC ASPECTS

Tele-ICU implementation is associated with significant upfront investments as well as ongoing operational costs. Economic value is added when the cost savings or revenue increases realized through tele-ICU outweigh combined investment and operational costs over time. The core equation 'Value = Quality/Cost' can be expanded by adding the element of 'Access to Care,' thereby creating a Quality–Cost–Access triangle, with the three sides of the triangle being Quality–Cost, Access–Cost and Quality–Access [19].

Cost savings of tele-ICU are realized directly through LOS reduction, which can lead to reductions in ICU variable costs, such as manpower and pharmaceutical expenses. Also, given that tele-ICUs can increase best practice adherence, like venous thromboembolism (VTE) prophylaxis, complications can be reduced and better pay-for-performance metrics achieved. Tele-ICUs can also lead to increases in revenue and increased case volume by allowing greater capacity without having to build more ICU beds.

Revenue increases are realized through improved acuity distribution, optimized throughput/bed utilization and capacity management, particularly in larger healthcare systems dependent on optimizing access across a spectrum of care from outpatient to community hospital to tertiary and quaternary care centers.

A recently published simulation analysis determined that tele-ICU implementation based on severity of illness likely improves tele-ICU cost effectiveness [20]. In the accompanying editorial, Ries [21] raises the importance of activity-based cost accounting to determine the return on investment for tele-ICUs.

The most comprehensive and robust experiential financial outcomes study to date was published last year (2017) by the University of Massachusetts/Worcester tele-ICU operation (2 campuses, 834 bed academic medical center), which has been operating since 2006 [22^{***}]. Lilly *et al.* used activity-based accounting methodology for this single center three phase before–after study. The primary outcome measure was change in annual direct contribution margin (aggregated net case revenue minus direct costs). The pretele-ICU intervention phase contained baseline preintervention outcomes and financial performance data on 14 257 patients from 2004 to 2006. The second phase contained data after tele-ICU implementation on 14 552 patients from 2006 to 2010. The final third phase added Logistics Center Functions to the tele-ICU intervention for 22 394 patients from 2010 to 2013. The Logistics Center functions were targeted at increasing access

to critical care and optimizing capacity/throughput as well as providing support for 51 care standardization projects. Tele-ICU support increased the direct ICU contribution margin by 376% from \$7.9 to \$37.6 million/year, decreased hospital LOS by 6.7% and increased case volume by 20.7%. Added Logistics Center functions increased the contribution margin to \$60.5 million/year, reduced hospital LOS by 15.4% and increased case volume by 38.5% compared with baseline. Per case costs initially increased because of tele-ICU implementation costs, but were recouped within 3 months because of increased operational efficiency. The significant increase in case volume was attributable to reduced ICU and hospital LOS, improved ICU bed utilization and throughput via tele-ICU-directed removal of impediments to timely ICU admission and discharge, thus accelerating transfers and increasing bed sharing across most ICU beds.

Care standardization efforts through a newly formed care standardization committee implemented a total of 51 separate projects ranging from patient experience to patient safety to care pathway modifications and overall were estimated to have reduced direct costs/case by 4.2%.

INTERHOSPITAL TRANSFERS

There is conflicting data as to whether tele-ICU implementation increases interhospital transfers [23,24] or decreases them [25]. A multitude of factors specific to the hub and spoke hospital settings and the healthcare systems in question likely determine the effect of Tele-ICU on this metric.

META-FACTORS AFFECTING SUCCESS

There are a multitude of factors that in aggregate shape the response of any given healthcare institution to tele-ICU implementation. They all address the 'How?' domain. Like any other intervention in medicine, tele-ICU implementation can either be supported and shaped to succeed or destined to fail depending on how these surrounding meta-factors are handled. A recent comprehensive ethnographic study by Khan *et al.* [26^{***}] confirmed our beliefs that domains surrounding leadership, perceived value of tele-ICU, change management strategies and organizational structure are most closely associated with success of tele-ICU implementation.

TRAINEE EDUCATION

A prior review in this journal on the future of anesthesiology raised the question as to whether we can utilize new technologies to provide supervision and

oversight in the critical care setting [27]. Most health-care providers graduating today irrespective of specialty are estimated to routinely use some form of telemedicine in their future clinical practice, yet systematic training in telemedicine for the next generation of physicians, nurses and allied health professionals on a global and national scale is only in its earliest stages. Few institutions have established structured telemedicine curricula, clerkships and clinical rotations for medical students, residents and fellows. As of November 2018, there are currently only four telehealth training programs accredited by the American Telemedicine Association (<https://www.americantelemed.org/main/ata-accreditation/training-programs>).

The Anesthesiology Residency Review Committee of the Accreditation Council for Graduate Medical Education and the American Board of Anesthesiology do not list any specific requirements for tele-ICU training in Anesthesiology or Anesthesia Critical Care. The AMA only offers an online course in the 'Practice Transformation Series' on 'Adopting Telemedicine in Practice.'

At our institution we have successfully developed a tele-ICU curriculum, 1-day clerkships for medical students, as well as 1-week and 1-month long clinical tele-ICU rotations for residents and fellows to enable our trainees to have structured exposure to this specific clinical care environment.

Apart from teaching the next generation the nuts and bolts of executing telemedicine, tele-ICU can also be used as a centralized education and clinical supervision tool for trainees, particularly after hours, when direct supervision by critical care attending is often limited. We have found our tele-ICU to be extremely useful in the direct supervision of nighttime ventilator management, bedside procedures and bedside point-of-care ultrasound (POCUS) examinations. Nighttime POCUS exams are often conducted by medical trainees with basic training but little experience, but frequently have huge treatment implications for patients. We have successfully used tele-POCUS supervision by the tele-ICU attending to standardize POCUS image acquisition and interpretation [28,29]. Others have shown that tele-ICU-directed ultrasound can even function with unskilled bedside operators guided by tele-intensivists who supervise image acquisition and handle image interpretation of focused critical care ultrasound [30].

RESEARCH POTENTIAL

Finally, the rich and granular data generated by most tele-ICU operations on a routine basis often includes risk predictive outcomes scores like Acute

Physiology, Age and Chronic Health Evaluation (APACHE) and/or acuity of illness scoring like Sequential Organ Failure assessment (SOFA), which can readily be harnessed to support medical trainee-driven research projects. On a national level, this has led to the formation and growth of a uniquely powerful clinical database for clinical research [31].

Numerous publications to date have already successfully used this dataset [32].

CONCLUSION

Evidence is expanding on the value of tele-ICU to improve meaningful clinical outcomes, financial performance metrics like case volume and direct contribution margin through optimized ICU bed utilization and capacity management. As with any other complex intervention, numerous meta-factors related to administrative buy-in and leadership, change management techniques and organizational structure surround tele-ICU implementation and operation and in aggregate crucially shape its ultimate success. Integration of tele-ICU into the educational curriculum for the next generation of medical providers is lagging behind the pace of expansion of its clinical role in healthcare.

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Conflicts of interest

There are no conflicts of interest.

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