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Pediatric Critical Care Medicine (MT Bigham and J Giuliano, Section Editors)

Telemedicine in Pediatric Critical Care: At Home and Abroad

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Opinion statement

This review highlights current efforts to expand telemedicine in pediatric critical care in the United States (U.S.), including the evolution of the underlying technology, and evaluates studies supporting its use. The important and growing role of telemedicine in resource-limited settings (RLS) is further outlined. Pediatric telecritical care is a rapidly growing field, with data emerging to assess its feasibility, cost-effectiveness, and clinical utility. Telemedicine is increasingly applied in RLS for both clinical and educational purposes—embraced as a means of overcoming longstanding barriers of distance, training, and technology. The use of telemedicine is increasing in the U.S. and around the world, with a growing body of evidence to support its use. More research is needed on the clinical impact of such programs. However, given its potential to save lives, time, and money, we recommend continued development and implementation of pediatric telemedicine programs to provide clinical support and critical care education for remote and resource-limited settings.

Introduction

Advances in digital and telecommunication technologies have revolutionized contemporary life. In many ways, the promise of these advances is only beginning to be realized in medicine, even as the state of the art is poised to make a further leap forward [1]. Remote or telemedicine overcomes gaps in distance, communication infrastructure, and even technology; erasing disparities in care and access [2–4]. It is an area of active clinical expansion and research, with 51 telemedicine-related journals and another 48 conferences worldwide, in addition to numerous societies and websites dedicated to telemedicine [5]. In this review, we will look at the various technologies applied and those on the horizon, the settings in which they are applied in the care of critically ill children, and the data supporting their use. Finally, we will outline how telemedicine is currently delivered in resource-limited settings, enabling caregivers and educators to leapfrog old barriers to providing care to critically ill children.

The development of remote medical care has been technology driven, with advances harnessed to meet need. The result of this trend has been the transmission of increasing amounts of data, over greater distances, at faster rates. Initially, telephone lines were exploited for these purposes, and by 1950, they permitted not only audio communication, but also the transmission of radiographs to perform "telognosis" [6]. Soon, radio and microwaves were manipulated to enable mobile communications and data sharing, such as telemetry [7–9]. Many of these advances were borrowed from technologies that the National Aeronautics and Space Administration (NASA) developed to continuously monitor astronauts and their microenvironment during space flight. These NASA technologies, land and satellite-based, soon found civilian application in mobile communications in the remote regions of Native American reservations in the United States (U.S.) and in rural Alaska [7, 10–12]. Pioneer applications of telemedicine can also be seen in the U.S. military, where various technologies demonstrated that they could function under "difficult geographic and climatologic circumstances," such as those found in the Persian Gulf War in 1991 [13]. By the late 1970s, there were "various technical configurations" utilizing diverse networks and "methods of transmission," ranging from land-based lines or coaxial cable, broadband transmission over laser or microwaves, line-of-sight stations, and satellite-based relay—all enlisted in the service of remote medical care [14].

Modern mobile technology has evolved through increasingly sophisticated generations of devices and communication networks. The first generation, 1G, launched the modern connectivity movement utilizing analog home telephone technology in cellular networks [15•, 16••]. These analog improvements, however, have been subsequently eclipsed by the momentous advances in semiconduction and microprocessing, which have fostered the progress in digital technologies, and a dramatically increasing bandwidth capacity [16••]. The first such digital system was 2G, which provided improved coverage and voice transmission quality, with new capacity for data transmission and the ability to encrypt [16••].

By the 1990s, 3G technology allowed packet data transmission which increased data transfer rates and, importantly, enabled the creation of a single global system that incorporated land-based cellular and satellite networks [15•, 17•]. These faster transmission rates permitted larger emails and video conferencing, greatly expanding cellular applications in telemedicine [18]. This trend of increasing mobile capacity continued with the advent of 4G, in conjunction with the further miniaturization of devices, creating progressively greater mobile capability [16••]. The newest networks to emerge are 5G, which are considered "transformative" in their global connectivity, and bound well beyond current capabilities in every measurable respect [1, 16••]. By way of comparison, a feature movie can be downloaded in 8 min using 4G networks, compared to 5 s with 5G networks [19]. The end result of these breakthroughs is the routine transmission of what had previously been considered unimaginably large amounts of quality data, almost instantaneously, without regard to distance. This, in turn, has ushered in a "transformation" of health care delivery in this country, facilitating data sharing, connecting patients and physicians, and physicians with other providers [20].

Remote PICU applications in the U.S.

The assumption of clinical benefit from pediatric telecritical/emergency care is attributed to studies showing that a critically ill child fares better in the care of a suitably trained intensivist [21, 22]. In addition, studies have suggested that general emergency departments (EDs) are more poorly equipped for pediatric patients and have fewer trained personnel prepared to manage critically ill children [23, 24]. Regionalization of resources and the closure of rural hospitals have also played a role in this process, creating regional centers serving larger catchment areas [25•]. In step with technological improvements, telemedicine programs have developed in number and sophistication in order to support the care of the severely ill child outside of academic medical centers. In pediatric critical care, remote medicine has been applied in essentially three settings, with obvious overlap: consultations with community EDs, critical care transport teams, and those providing care in non-pediatric intensive care units (ICUs) or community hospital wards. These consultations are provided in different formats, but broadly speaking are either active (continuous or synchronous) or passive (consultative or episodic) with varying lag times [26].

Deploying technology to assist with the care of critically ill patients in the field was one of the earlier and most important developments in telemedicine, particularly in the fields of trauma and myocardial infarction [9]. The feasibility and potential of broadband audiovisual telemedicine to facilitate pediatric critical care transport was initially investigated nearly 20 years ago [27]. The use of telemedicine in the transport of critically ill children continues to be evaluated, and subjective assessments of its utility in this domain have been favorable [28]. Utilizing the increasingly user-friendly technologies, such as FaceTime©, is also being explored [29].

As is often the case, application (and study) of telemedicine in pediatrics has lagged behind adults, where 13% of U.S. adult medical ICU beds are telemanaged [30]. Pediatric telemedicine has grown over the past several years, and in 2013, at least 15 children's medical centers provided formal remote teleconsultations to EDs that lack pediatric subspecialty care [31]. This growth has accelerated, and as of 2015, there were approximately 50 pediatric telemedicine programs in the U.S., per a national survey [32]. The exact number of formal pediatric critical care telemedicine programs is not known, although one assumes teleconsulting on some level is present in most pediatric ICUs.

The principle model described is consultative, where remote video consultations have aided with triage, diagnosis, treatment, and decisions on medications dosing [33–35]. These services have also addressed the often difficult decision of transfer of care [36, 37]. This is an area of particular relevance since nearly 8% of the 28 million children seen in EDs across the country are transferred during the course of their care to EDs or hospitals with greater pediatric expertise [31]. Additionally, pediatric intensive care unit (PICU) consultations have been employed to assist ward patients in hospitals without pediatric critical care support, pediatric trauma patients admitted to adult ICUs, between tertiary PICUs and non-tertiary PICUs, with facilities lacking 24-h in-house attending support, and even to direct resuscitation efforts [38, 35, 36, 39•, 40, 41]. Studies have not addressed the use of more continuous models of PICU consultation, nor integrative approaches, including the intriguing promise of remote ventilator management [42].

Medico-legal implications of telemedicine

The development of telemedicine programs in the U.S. has been hampered by the novel medico-legal issues that have arisen, particularly those related to licensure, medical liability, and privacy [26]. The questions raised affect both individual providers and programs at large. Currently, the state medical boards, which control credentialing and licensing, represent barriers to the interstate adoption of telemedicine because they issue licenses based on the location of the patient-physician contact [43, 26]. An alternative, more uniform approach to this problem is lacking [43]. Thirty-three states have addressed the issue of telemedicine practice across state lines, but only eight have authorized "special purpose" licenses for cross-state telemedicine practice, the remaining 21 requiring full state licensure [44, 2]. These licensing issues, specific to the practice of telemedicine in the USA, are even more variable in international telemedicine where, in some cases, individual pre-implementation assessment is required [45].

The U.S. Federal government has attempted to foster the growth of telemedicine by addressing licensing and other problems [26]. Both the Joint Commission and the Center for Medicare and Medicaid services have supported the interstate practice of telemedicine, partially through "credentialing by proxy," thus allowing a central hospital to share its credentialing with the satellite hospitals. However, this privilege comes with the proviso that the state where the patient resides retains responsibility for the quality of the care provided through the telemedicine service [43]. Additionally, it is required that both entities providing and receiving telemedicine consults ensure that each state's accrediting agency's requirements are met, often resulting in time-consuming redundancy [43]. Lastly, this option of shared credentialing is not often utilized, as many community-based hospitals are wary to expose themselves to the liability risks [2].

Medical liability remains a further medico-legal concern in telemedicine [26]. According to Burke et al., telemedicine liabilities issues include the following: defining the physician-patient relationship, roles and communication responsibilities of each party, patient abandonment, technological failures, liability insurance, and malpractice jurisdiction, among others [2]. A physician-patient relationship has been considered to have been established during telemedicine interactions, and thus, the same rules for that privileged relationship apply [2]. Some legal experts worry that telemedicine may be open to the same liability issues as have been established for telephone cases [44]. A review of telephone malpractice cases found many interventions had led to serious injuries with costly settlements [46].

A final serious and complicated medico-legal question in telemedicine is how to best assure the security of personal health information (PHI). Each remote interaction is required by law to comply with the Health Insurance Portability and Accountability Act (HIPPA) of 1996 and other regulatory requirements [2]. The sharing of PHI between mobile health (mHealth) providers over the internet using devices such as smartphones is increasing, and aside from the security risks involved, patients may be left with little control/assurance of what is being shared and with whom [44]. A recent paper looked at privacy risks when using mHealth applications and noted that only 15% of mHealth and fitness applications were communicated with appropriate encryption [47]. Further, 90% of these mobile health applications communicate with a server, resulting in sharing of your health data without informed permission [47].

These complex medico-legal issues, among others, require thoughtful evaluation prior to the implementation of any telemedicine program [2]. The form and function of remote medicine in the future will be influenced by how these issues are resolved.

Evaluations of pediatric telemedicine

As telemedicine is only one piece of a complex clinical picture, isolating and demonstrating its benefits has been challenging [48]. In fact, the evidentiary support behind telemedicine programs has lagged somewhat behind its enthusiastic application. Even in adult critical care, with a greater wealth of data on remote care, there remain ambiguous results [49, 50]. In fact, evaluations have been hindered by methodological problems, including variability in the interventions themselves (exact types of technologies applied, "dose" of applications, etc.), variable target settings (level of hospitals, hospital "cultures," etc.), and heterogeneity in local caregivers and patients [51, 25•, 49]. These methodological problems are also present in pediatrics where, although data is accumulating, the clinical benefits of telemedicine have not yet been convincingly demonstrated [52].

In pediatrics, most evaluations on the effects of remote medicine in various settings have focused principally on issues of feasibility, provider/patient/parent satisfaction (including parent stress level), clinical equivalence in assessments, and some limited measures of effectiveness [38, 39•, 28, 34, 53, 54, 55•]. In the realm of transport for example, there are no data demonstrating a clinical or cost benefit of real-time, audiovisual communication between transport teams and intensivists [29]. Even in adult studies, benefits in active transport have only been shown in simulated patients [56]. Specifically, in teleconsultation to the ED, studies have shown some benefit in the overall "quality" of care [34, 28].

There is only modest data on benefits to clinical status or PICU outcomes, although study of remote partnering with rural neonatal ICUs (NICUs) has shown decreased hospital length of stay and mortality [57, 53]. Remote PICU consults to rural and community hospitals have also led to a reduction in the number of transfers and in hospital and ICU lengths of stay for transferred infants and neonates with congenital heart disease [57, 36]. However, a recent retrospective cohort study associated the implementation of a telemedicine program (consisting of audiovisual communications between the patient and the local care team and the remote physician) with favorable clinical/physiologic patient status upon PICU admission (as measured by PRISM II), compared to those coming from EDs without telemedicine access [58•]. This is an important first step in demonstrating the potential clinical benefits of critical care telemedicine in the care of children [59].

Newer diagnostic capabilities in telemedicine technology

Aside from the structure and setting of telemedicine consultations, the improving bandwidth and vastly enhanced image quality allow increasingly widespread medical application of these technologies. The potential stretches from more traditional data/image sharing and interactive video consulting or conferencing, to remote use of diagnostic aides like stethoscopes, ophthalmoscopes, and ultrasonography [2, 60, 61]. Ultimately, the integration of these data has near-limitless potential for clinical application.

Synchronous telesonography is, in fact, becoming a reality as the fine anatomical details transmitted have become adequate to make diagnoses, and the real-time aspect allows for the remote expert to direct the local ultrasonographer to obtain further views to improve the diagnostic accuracy [61, 62]. When combined with a robotic arm, which mimics the movement of the expert's hands, even remote abdominal telesonography has been shown to be reliable [63]. Remote echocardiography (echo) has also been demonstrated to be both feasible and reliable [64]. U.S. pediatric cardiologists are using remote echo performed by primary care physicians to distinguish between neonates suspected of having congenital heart disease (CHD) requiring immediate surgical repair and those who could be medically managed [64]. Other studies have reviewed the accuracy, feasibility, and acceptability of performing remote fetal echocardiograms with teleconferencing. One report concluded that fetal echoes could help diagnose and exclude CHD remotely [65]. In all of the above examples, data from diagnostic tools in the hands of local providers was able to be evaluated by remote specialists who could then guide treatment decisions.

The many possible groundbreaking applications of the high image quality and speed of 5G will not just be information sharing and diagnostics, but also instructional and therapeutic [1]. In the near future, because of broadband's ability to transfer large files with high fidelity in seconds, specialists could guide physicians in remote areas through advanced procedures such as pericardiocentesis, thoracocentesis, and paracentesis [66]. Although the connectivity will need to be assured, one study was able to show that the "willingness of the on-site provider to listen, pay attention, and to respond to direction of the remote expert" demonstrated remote instruction to be feasible, even with lay persons [67].

Remote PICU applications in resource-limited settings

If the promise of telemedicine is its potential to remedy the "inaccessibility to care, shortage in human health resources, the uneven distribution of resources; rising costs; and the uneven levels of quality of care" in medicine, then nowhere is it more relevant than in resource-limited settings (RLS) [14, 68]. The disparity between the high incidence of critical illness and the lack of capacity and trained personnel is striking, particularly when considered graphically [68, 3, 69]. Over time, this recognition has led to a reassessment of both the ethical and financial objections to providing advanced care in these constrained settings [68, 3, 48, 25•]. Moreover, the imbalance of caregivers and patients is now understood as the primary barrier to providing critical care in RLS [69].

The use of telemedicine offers opportunities to directly address this shortcoming in meaningful ways by providing experienced, specialized support for these providers [3, 68]. In addition to this potential to improve outcomes through timely recommendations, telemedicine programs could reduce cost to families and institutions by advising on the admission and/or transfer of sick children [68, 25•, 70]. The further application of these technologies for educational purposes can also indirectly impact patient care. It is for these reasons, and multiple others, that expanding information and communications technologies is felt by some to be "central to the improvement of life in developing countries" and named as a Millennial Development Goal [71, 72].

Important technical considerations remain regarding both the consistency of connectivity and the availability of bandwidth—i.e., quality of the content—in developing countries. The "digital divide," though improving, remains [72]. Nonetheless, successful telemedicine experiences have been observed even with low-bandwidth, "store and forward" data [73]. In the final analysis, the "best" model for a given facility or region is a function of many of the above factors, as well as limitations of the health care systems themselves, and the varying needs of the local population [74]. Regardless of the approach, the assumption of benefit from telemedicine in resource-limited settings is being tested through many pilot studies conducted by international groups and their local partners. Out of these efforts, a growing body of evidence supports its value, both for clinical and for educational purposes [75–80, 3, 68, 81].

Clinical applications

Médecins Sans Frontières (MSF) has been in the vanguard of clinical application of telemedicine technologies around the world, many of which are useful in the care of the critically ill child. In 2010, for example, they established a teleconsultation platform, available through their internal website to all of the health care providers in their system [76]. Currently, the telemedicine service has conducted more than 3000 consults since its inception, of which 40% were for children [79, 76]. Although rated "helpful" in three-quarters of the cases, this passive approach has the drawback of a relatively prolonged lag time, with a median time of 13 hours between the placement of the consult question and the expert's response [79]. A different MSF project offers active consultation between providers caring for children at a Somalian district hospital and a pediatrician in Nairobi [81]. This direct method of teleconsultation demonstrated a range of significant benefits, from decreased losses to follow-up, improved detection of a previously unrecognized life-threatening illness in 25% of consultations, a change in management of the patient in 64% of cases, to significant reduction in adverse outcomes like death [81].

The Medical Missions for Children (MMC) has created another vibrant global network. Their telemedicine platform, called the Global Telemedicine and Teaching Network, is active in 108 countries and has served over 80,000 children in the last 15 years [82–84]. This network offers both international collaborations and supports the growth of national networks, like the SIG Health for Children in Brazil that connects 44 hospitals and 650 providers [83, 82, 85]. Through the Telemedicine Outreach Programme, consultations are available for critically ill children and those with other needs requiring subspecialty attention [86]. MMC has also introduced advanced technologies, such as Telephonic Stethoscope for remote auscultation to facilitate physical diagnosis [82].

As seen with MSF and MMC, most international telemedicine programs are available for all patients in the participating facilities. Unfortunately, there are limited telemedicine programs focusing exclusively on the care of critically ill children in RLS. A joint U.S.-Latin American pediatric cardiac ICU (CICU) program relies on real-time data sharing and active consultations by U.S. cardiac intensivists who offer recommendations on surgical strategies, arrhythmia management, and the need for cardiac catheterization [87]. This partnership has been found to be not only feasible, with high provider satisfaction, but also to result in shorter lengths of stay in the CICU and the hospital [80, 87, 78•]. The U.S. military employs a critical care-specific platform called Virtual Critical Care Consult (VC3) service. VC3 is available to Special Operations Forces medics and provides real-time support with direct communication via phone or email with intensivists [88]. A study detailing the VC3 program reports that "the VC3 pilot program has been extensively tested in field training exercises and validated in several real-world encounters" [88]. While this service focuses on the care of U.S. soldiers injured in conflict areas, there is the possibility of applicability in caring for civilian casualties, including children.

The multidisciplinary needs of the critically ill can be addressed by other remote consultation services. A telemedicine program in Nepal provides a wide range of subspecialty consultations, and implementation of remote care into rural regions across the wide land mass of China has been shown to be feasible and financially advantageous [77, 89]. A study in Kenya showed that nurse medical advice via teleconsultation was the same as that given in face-to-face encounters in nearly 90% of cases, supporting the near equivalency of remote care, available without the many barriers of travel [90]. More specifically, the use of teleradiology helps to ameliorate the severe shortage of radiologists in some regions, including those without a single in-country radiologist [91]. The remote evaluation of imaging results in earlier and more appropriate interventions, including the possibility of real-time abdominal ultrasonography (FAST exam) for trauma patients [92, 91]. Currently, there are fledgling teleradiology services in India and Africa, supported by the World Federation of Pediatric Imaging (WFPI) [91]. MSF is also active in providing teleradiology, both through their structured platform-based service and through volunteer radiologists reviewing imaging from several MSF field projects [91]. Finally, a Malawian study found that assessment of burns with digital photography was valid and affordable, with appropriate correlation between photographs and in-person assessment [93].

Educational applications

The dearth of up-to-date textbooks, library facilities, not to mention salaried faculty, leaves gaps in medical education that can be filled by virtual or remote education [94, 3, 68]. It is well recognized that any program targeting sustainability must include an educational component, whether explicit or interwoven into the clinical program [3, 69]. The link between critical care education and improvements in care has been emphasized by those working in the field [69, 3]. There is, in fact, evidence that telemedicine consults not only improve clinical care but also have an educational impact—a form of "bedside" teaching [81]. More specifically, these benefits include an increased capacity of local providers to independently deliver complex care, with progressively fewer changes made to initial management plans for common consults [81].

Concretely, on-line curricula are being used to facilitate the training of emergency and pediatric critical care physicians in Africa, specifically the already established African Federation of Emergency Medicine Program and the Seattle Children's-Nairobi PECC Program, which will be launched soon [94]. It is believed that remote teaching the basics of critical care, i.e., managing the ABCs—airway, breathing, circulation—and a framework for common medical emergencies, will reduce child mortality in RLS [4]. MSF is also one of a number of organizations active in deploying the telemedicine technologies for educational purposes, many of them connecting through the Collegium Telemedicus (CT) system [95]. CT aims to facilitate the transfer of knowledge and expertise between networks of providers in remote or low-resource areas [95]. Nearly 30 organizations make use of CT systems, including MSF and WFPI [95].

There are numerous other independent programs that focus on education through telemedicine technology, including the Global Health Delivery Project (GHDP), MMC, and Project ECHO (Extension for Community Health Care Outcomes). The GHDP directly addresses this need for education among health care providers in RLS by providing free RLS-specific case studies and educational courses to anyone who accesses their website [96]. MMC's second major mission, beyond direct clinical care, is to promote education, which is done principally through its Global Video Library of Medicine, with over 50 video conferences available per month [84, 86]. Project ECHO is an innovative "hub-and-spoke" telementoring program in over 20 countries that uses didactic and case-based presentations via video conferencing technology to connect primary care providers in rural and underserved areas with specialty care providers at "hub" academic medical centers [97–100]. All of these various educational platforms focus on connecting content experts with local providers to increase the capacity of local systems to care for their patients and work towards decreasing health disparities.

Conclusion

Technological advances have allowed for dramatic increases in the capabilities of remote or telemedicine, both in the care of critically ill children and education. Programs focused on the remote care of the severely ill or injured child proliferate in the U.S., where data supporting the advantages of its applications are growing. Further innovations portend even greater capacity in the coming years. In resource-limited settings, telemedicine has the potential to help overcome many barriers to providing pediatric critical care, including medical management and clinician education.

Compliance with Ethical Standards

Conflict of Interest
The authors declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent
This article does not contain any studies with human or animal subjects performed by any of the authors.

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