Using Telemedicine to Improve Access to Subspecialty Care for Underserved Children

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ABSTRACT

The national shortage of pediatric subspecialists such as pediatric critical care physicians and pediatric neurologists, coupled with their regionalization at urban, tertiary-care children's hospitals has created geographical disparities in access to care, leaving patients residing in remote and rural communities medically underserved. In the inpatient setting, lack of pediatric critical care specialists at rural and community emergency departments (EDs) has been shown to adversely impact care, resulting in higher illness severity of patients when transferred to a Pediatric Intensive Care Unit (PICU). Higher illness severity is associated with higher morbidity, higher mortality, longer lengths of hospital stays, and higher resource utilization. In the outpatient setting, lack of subspecialists such as pediatric neurologists, forces patients and their families living in rural communities to travel long distances for care. Travel-related hardships such as missed work and transportation costs put children at greater risk of missing their scheduled medical appointments. Missing appointments leads to inconsistencies in necessary care and could result in poorer health outcomes as well as extra visits to the Emergency Department (ED) or preventable hospitalizations.

Telemedicine consultations are being increasingly utilized to address disparities in the access to subspecialists. UC Davis Children's Hospital (UCDCH) has been providing telemedicine consultations to children living in rural communities in nearly 25 different inpatient and outpatient subspecialties for more than two decades. The aim of this dissertation was to evaluate the effectiveness of an inpatient (pediatric critical care) and an outpatient (pediatric neurology) model of care delivered using telemedicine to generate evidence regarding its feasibility as a potential solution to the problem of access in underserved regions.

In Chapter 1, we evaluated the pediatric critical care telemedicine program where referring, non-pediatric EDs obtain telemedicine consultations for critically ill children. Specifically, we evaluated the impact of this program on the severity of illness of children arriving to UCDCH's PICU between 2010 and 2014, hypothesizing that the telemedicine program would result in better care and lower severity of illness upon arrival. This retrospective cohort study included 582 patients from 15 EDs with telemedicine and 524 patients from 60 EDs without telemedicine. We found that children transferred from EDs with telemedicine capabilities were significantly less sick upon arrival to the PICU (Pediatric Risk of Mortality, PRISM III score 3.2 vs. 4.0, $p<0.05$), even after adjusting for confounders (mean PRISM III score 0.74 units lower, 95% CI: –1.46 to –0.02) suggesting more appropriate stabilization of children transferred from EDs with telemedicine capabilities. We also found that standardized mortality ratios (Observed / Expected ratios) were lower than 1.0 for children admitted from EDs with telemedicine (0.81, 95% CI, 0.53–1.09), and higher than 1.0 for children admitted from EDs without telemedicine (1.02, 95% CI, 0.71–1.33). These findings suggest that access to pediatric critical care specialists over telemedicine during the initial treatment of children in non-pediatric EDs might offer an opportunity to reduce morbidity and mortality.

In Chapter 2, we evaluated a pediatric neurology telemedicine program where pediatric patients were seen in their own community clinic by the pediatric neurologists at UCDCH over telemedicine. We compared appointment completion rates between the telemedicine pediatric neurology clinics and the in-person UCDCH pediatric neurology clinics. We sought to determine whether outpatient telemedicine improves access to care for underserved patients. Using data from electronic medical records, we analyzed 1,158 telemedicine appointments by 381 patients and 13,311 in-person appointments by 3,791 patients scheduled with UCDCH pediatric neurologists between 2009 and 2017. We found that children completed 73% of their scheduled appointments in the telemedicine clinics and 65% of their scheduled appointments in the usual care, in-person clinics. Even after adjusting for various potential confounders, we found the odds of visit completion to be 57% higher in the telemedicine clinics than the in-person clinics.

In Chapter 3, we evaluated the impact of the same outpatient pediatric neurology telemedicine program on patients' utilization of hospital services. We found the rate of all-cause hospital encounters to be nearly four times lower among children who received pediatric neurology consultations over telemedicine in their local communities compared to children who received care by travelling to the urban, in-person clinics located on-site at UCDCH (5.7 vs. 20.1 per 100 patient-years, respectively; $p<0.001$). We also found the rates of neurological condition-related hospital encounters to be almost twice as low among the telemedicine cohort compared to the in-person cohort (3.7 vs. 8.9 per 100 patient-years, respectively; $p<0.001$). Our finding of lower hospital use among the telemedicine cohort remained significant and consistent even after adjusting for confounders including insurance status, median household income, travel time to UCDCH, neurology clinic diagnoses and the presence of a complex chronic condition.

In conclusion, our results suggest that the use of telemedicine to treat children living in rural communities for selected specialties in acute and outpatient care is associated with improved clinical outcomes, better appointment adherence, and lower hospital utilization. Our study adds to the limited but growing body of research confirming the effectiveness of subspecialty telemedicine care for children in rural and underserved communities.

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INTRODUCTION

Regionalization of pediatric subspecialty care has led to the clustering of scarce providers at tertiary-care children's hospitals located in urban areas.[1-3] While regionalization aims to increase efficiency and quality of care at major referral centers, it also creates geographical disparities in access to subspecialty care, leaving remote and rural communities, distant from children's hospitals, medically underserved.[2-4]

Pediatric critical care is a case in point. Only 10% of hospitals in the U.S. have both an Emergency Department (ED) and Pediatric Intensive Care Unit (PICU) to evaluate and manage critically ill or injured children.[5,6] A majority of children receive emergency medical care in rural, community, and otherwise non-children's hospitals.[6-8] Regionalization of pediatric specialty care at children's hospitals and lower annual pediatric volumes at non-children's hospitals make it difficult for these hospitals to maintain sufficient infrastructure and clinical staff specialized in the care of seriously ill children, which may impact the patients' clinical outcomes.[7,9-12] Previous studies have shown that the children transferred from general and community hospital EDs receive poorer care and have higher severity of illness upon presentation to a PICU compared to children transferred from EDs within children's hospitals that house the PICU.[13-17] Higher severity of illness is associated with higher morbidity [15,16,18,19], higher mortality, [13,15,20-22] longer lengths of hospital stays,[13,18] and higher resource utilization.[13,18,22,23]

Real-time telemedicine consultations are being increasingly utilized to address disparities in access to pediatric subspecialists in underserved communities. A telemedicine consultation is live, audiovisual interactive communication between a subspecialist at a children's hospital and the patient, parent/guardian and referring provider (remote ED physician or primary care physician) located at a remote site. UC Davis Children's hospital (UCDCH) has been providing consultations using telemedicine in nearly 25 different inpatient and outpatient subspecialties since 1996. Nearly 2,800 telemedicine consultations are provided every year at clinics and hospitals across UCDCH's 33-county service area in Northern California.[36]

The Pediatric Critical Care Telemedicine Program at the UCDCH was initiated in 2000 and provides telemedicine consultations to approximately 8.6% of the critically ill pediatric patients transferred from participating referring EDs.[37] Data from previous research has demonstrated that the use of telemedicine to support the care of seriously ill children at referring EDs results in higher provider and patient satisfaction,[38-41] improved clinical outcomes,[42] fewer medication errors,[11] and higher quality of medical care. [39,43] Pediatric telemedicine consultations can sometimes obviate unnecessary transfers, [42-45] facilitate timely and appropriate stabilization prior to and during the transfer process, [44,45] and may result in lower severity of illness upon admission to the PICU, resulting in improved outcomes. While many critical care telemedicine programs have been implemented in the recent past, few studies have evaluated their impact on clinical outcomes.

Disparities in access to pediatric subspecialists are also substantial in outpatient settings. Among all medical specialties, neurology has one of the highest shortages of specialists.[24] A recent study estimated that an additional 20% of pediatric neurologists are needed to fully meet current clinical needs and this shortage is projected to persist or worsen in the coming decade.[24] Confounding these shortages is the fact that pediatric subspecialty care is very regionalized,[25-27] forcing children with neurological disorders and their families living in rural communities to travel long distances to see the nearest pediatric neurologist. Hardships associated with travel – including missed work, missed school, and high transportation costs put these children at greater risk of missing their scheduled medical appointments and receiving less coordinated care.[28-31]

Inconsistent subspecialty care, in turn, can result in poorer health outcomes, as well as extra visits to the ED or preventable hospitalizations.[32-35]

In the outpatient pediatric neurology clinics, real-time telemedicine consultations reduce the time and financial burden of subspecialty visits for rural families, and could improve appointment completion rates and access to pediatric neurology care in underserved communities.[28,46] UCDCH has been providing pediatric neurology services through telemedicine since 2009, completing more than 1,000 new and follow-up appointments at 15 remote sites in California. Whether outpatient telemedicine models of care can improve access for underserved populations and whether the increased access to care from telemedicine results in a reduction in hospital encounters such as ED visits or hospital admissions is not well studied.[26,47-50]

The aim of this dissertation was to evaluate the use of telemedicine as an intervention to improve access to subspecialty care for children residing in remote, underserved areas of Northern California. In Chapter 1, we evaluated the effectiveness of telemedicine in the inpatient setting by comparing the severity of illness among seriously ill children admitted to UCDCH PICU from EDs with and without access to pediatric critical care consultations using telemedicine. In Chapter 2, we evaluated the impact of telemedicine on access to pediatric neurology care by comparing appointment completion in the remote telemedicine clinics and the on-site, in-person clinics at UCDCH. In Chapter 3, we evaluated whether outpatient telemedicine models of care impact patients' utilization of hospital services by comparing the rates of ED visits and hospital admissions between similar patients with neurological conditions who obtained care at remote telemedicine clinics and those who obtained care at the on-site, in-person clinics at UCDHCH.

REFERENCES

1. Rimsza ME, Hotaling AJ, Moskowitz WB, et al. The Use of Telemedicine to Address Access and Physician Workforce Shortages. *Pediatrics* 2015;136(1):202-209.
2. Marcin JP, Shaikh U, Steinhorn RH. Addressing health disparities in rural communities using telehealth. *Pediatric Research* 2016;79(1):169-176.
3. Pletcher BA, Rimsza ME, Cull WL, Shipman SA, Shugerman RP, O'Connor KG. Primary care pediatricians' satisfaction with subspecialty care, perceived supply, and barriers to care. *J Pediatr* 2010;156(6):1011-1015 e1011.
4. Lorch SA, Myers S, Carr B. The Regionalization of Pediatric Health Care. *Pediatrics* 2010;126(6):1182-1190.
5. Remick K, Kaji AH, Olson L, et al. Pediatric Readiness and Facility Verification. *Ann Emerg Med* 2015.
6. Gausche-Hill M, Ely M, Schmuhl P, et al. A National Assessment of Pediatric Readiness of Emergency Departments. *Jama Pediatrics* 2015;169(6):527-534.
7. Athey J, Dean JM, Ball J, Wiebe R, Melese-d'Hospital I. Ability of hospitals to care for pediatric emergency patients. *Pediatric Emergency Care* 2001;17(3):170-174.
8. Kanter RK. Regional variation in child mortality at hospitals lacking a pediatric intensive care unit. *Critical Care Medicine* 2002;30(1):94-99.
9. Chamberlain JM, Krug S, Shaw KN. Emergency care for children in the United States. *Health Aff (Millwood)* 2013;32(12):2109-2115.
10. Tilford JM, Simpson PM, Green JW, Lensing S, Fiser DH. Volume-outcome relationships in pediatric intensive care units. *Pediatrics* 2000;106(2):289-294.
11. Dharmar M, Kuppermann N, Romano PS, et al. Telemedicine consultations and medication errors in rural emergency departments. *Pediatrics* 2013;132(6):1090-1097.
12. Dharmar M, Marcin JP, Romano PS, et al. Quality of care of children in the emergency department: association with hospital setting and physician training. *J Pediatr* 2008;153(6):783-789.
13. Odetola FO, Rosenberg AL, Davis MM, Clark SJ, Dechert RE, Shanley TP. Do outcomes vary according to the source of admission to the pediatric intensive care unit? *Pediatric Critical Care Medicine* 2008;9(1):20-25.
14. Odetola FO, Davis MM, Cohn LM, Clark SJ. Interhospital transfer of critically ill and injured children: an evaluation of transfer patterns, resource utilization, and clinical outcomes. *J Hosp Med* 2009;4(3):164-170.
15. Gregory CJ, Nasrollahzadeh F, Dharmar M, Parsapour K, Marcin JP. Comparison of critically ill and injured children transferred from referring hospitals versus in-house admissions. *Pediatrics* 2008;121(4):E906-E911.
16. Odetola FO, Clark SJ, Gurney JG, Dechert RE, Shanley TP, Freed GL. Effect of interhospital transfer on resource utilization and outcomes at a tertiary pediatric intensive care unit. *Journal of Critical Care* 2009;24(3):379-386.
17. Evans JM, Dayal P, Hallam DL, et al. Illness Severity of Children Admitted to the PICU From Referring Emergency Departments. *Hosp Pediatr* 2018;8(7):404-409.
18. Golestanian E, Scruggs JE, Gangnon RE, Mak RP, Wood KE. Effect of interhospital transfer on resource utilization and outcomes at a tertiary care referral center. *Crit Care Med* 2007;35(6):1470-1476.

19. Odetola FO, Mann NC, Hansen KW, Patrick S, Bratton SL. Source of admission and outcomes for critically injured children in the mountain states. *Arch Pediatr Adolesc Med* 2010;164(3):277-282.
20. Combes A, Luyt CE, Trouillet JL, Chastre J, Gibert C. Adverse effect on a referral intensive care unit's performance of accepting patients transferred from another intensive care unit. *Crit Care Med* 2005;33(4):705-710.
21. Durairaj L, Will JG, Torner JC, Doebbeling BN. Prognostic factors for mortality following interhospital transfers to the medical intensive care unit of a tertiary referral center. *Critical Care Medicine* 2003;31(7):1981-1986.
22. Hill AD, Vingilis E, Martin CM, Hartford K, Speechley KN. Interhospital transfer of critically ill patients: demographic and outcomes comparison with nontransferred intensive care unit patients. *J Crit Care* 2007;22(4):290-295.
23. Pollack MM, Patel KM, Ruttimann UE. Pediatric critical care training programs have a positive effect on pediatric intensive care mortality. *Critical Care Medicine* 1997;25(10):1637-1642.
24. Dall TM, Storm MV, Chakrabarti R, et al. Supply and demand analysis of the current and future US neurology workforce. *Neurology* 2013;81(5):470-478.
25. Timpano F, Bonanno L, Bramanti A, et al. Tele-Health and neurology: what is possible? *Neurological Sciences* 2013;34(12):2263-2270.
26. Davis LE, Coleman J, Harnar J, King MK. Teleneurology: successful delivery of chronic neurologic care to 354 patients living remotely in a rural state. *Telemed J E Health* 2014;20(5):473-477.
27. Kang PB, Bale JF, Jr., Mintz M, et al. The child neurology clinical workforce in 2015: Report of the AAP/CNS Joint Taskforce. *Neurology* 2016;87(13):1384-1392.
28. Bashiri M, Greenfield LJ, Jr., Oliveto A. Telemedicine Interest for Routine Follow-Up Care Among Neurology Patients in Arkansas. *Telemed J E Health* 2016;22(6):514-518.
29. Dantas LF, Fleck JL, Cyrino Oliveira FL, Hamacher S. No-shows in appointment scheduling - a systematic literature review. *Health Policy* 2018;122(4):412-421.
30. McLeod H, Heath G, Cameron E, Debelle G, Cummins C. Introducing consultant outpatient clinics to community settings to improve access to paediatrics: an observational impact study. *BMJ Qual Saf* 2015;24(6):377-384.
31. Velasquez SE, Chaves-Carballo E, Nelson EL. Pediatric Teleneurology: A Model of Epilepsy Care for Rural Populations. *Pediatr Neurol* 2016;64:32-37.
32. Patel AD. Variables associated with emergency department and/or unplanned hospital utilization for children with epilepsy. *Epilepsy Behav* 2014;31:172-175.
33. Patel AD, Wood EG, Cohen DM. Reduced Emergency Department Utilization by Patients With Epilepsy Using QI Methodology. *Pediatrics* 2017;139(2).
34. Patel AD, Terry D, Moore JP, et al. Reduction of emergency department visits using an urgent clinic for children with established epilepsy. *Neurology-Clinical Practice* 2016;6(6):480-486.
35. Nourazari S, Hoch DB, Capawanna S, Sipahi R, Benneyan JC. Can improved specialty access moderate emergency department overuse? Effect of neurology appointment delays on ED visits. *Neurology-Clinical Practice* 2016;6(6):498-505.
36. UC Davis Pediatric Telemedicine Program. UC Davis Children's Hospital 2018. Available at:

https://health.ucdavis.edu/children/clinical_services/pediatric_telemedicine/index.html. Accessed December 14, 2018.
37. Hernandez M, Hojman N, Sadorra C, et al. Pediatric Critical Care Telemedicine Program: A Single Institution Review. *Telemed J E Health* 2015.
38. Yang NH, Dharmar M, Hojman NM, et al. Videoconferencing to reduce stress among hospitalized children. *Pediatrics* 2014;134(1):e169-175.
39. Dharmar M, Romano PS, Kuppermann N, et al. Impact of Critical Care Telemedicine Consultations on Children in Rural Emergency Departments. *Critical Care Medicine* 2013;41(10):2388-2395.
40. 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. *Journal of Pediatrics* 2004;144(3):375-380.
41. Ray KN, Demirci JR, Bogen DL, Mehrotra A, Miller E. Optimizing Telehealth Strategies for Subspecialty Care: Recommendations from Rural Pediatricians. *Telemed J E Health* 2015;21(8):622-629.
42. Webb CL, Waugh CL, Grigsby J, et al. Impact of Telemedicine on Hospital Transport, Length of Stay, and Medical Outcomes in Infants with Suspected Heart Disease: A Multicenter Study. *Journal of the American Society of Echocardiography* 2013;26(9):1090-1098.
43. Yang NH, Dharmar M, Kuppermann N, et al. Appropriateness of disposition following telemedicine consultations in rural emergency departments. *Pediatr Crit Care Med* 2015;16(3):e59-64.
44. LaBarbera JM, Ellenby MS, Bouressa P, Burrell J, Flori HR, Marcin JP. The Impact of Telemedicine Intensivist Support and a Pediatric Hospitalist Program on a Community Hospital. *Telemedicine and E-Health* 2013;19(10):760-766.
45. Heath B, Salerno R, Hopkins A, Hertzig J, Caputo M. Pediatric critical care telemedicine in rural underserved emergency departments. *Pediatric Critical Care Medicine* 2009;10(5):588-591.
46. Adams JL, George BP, Dorsey ER. Neurologic care ... anytime? *Neurology-Clinical Practice* 2016;6(6):472-474.
47. Rasmusson KA, Hartshorn JC. A comparison of epilepsy patients in a traditional ambulatory clinic and a telemedicine clinic. *Epilepsia* 2005;46(5):767-770.
48. Halterman JS, Fagnano M, Tajon RS, et al. Effect of the School-Based Telemedicine Enhanced Asthma Management (SB-TEAM) Program on Asthma Morbidity: A Randomized Clinical Trial. *JAMA Pediatr* 2018:e174938.
49. McConnochie KM, Wood NE, Herendeen NE, et al. Acute illness care patterns change with use of telemedicine. *Pediatrics* 2009;123(6):e989-995.
50. Guttmann-Bauman I, Kono J, Lin AL, Ramsey KL, Boston BA. Use of Telehealth Videoconferencing in Pediatric Type 1 Diabetes in Oregon. *Telemedicine and E-Health* 2018;24(1):86-88.

Chapter 1

Impact of Telemedicine on Outcomes among Children Transferred from Referring Emergency Departments to a Children's Hospital Pediatric Intensive Care Unit

ABSTRACT

Objective: To compare the severity of illness and outcomes among children admitted to a Children's Hospital Pediatric Intensive Care Unit (PICU) from referring Emergency Departments (EDs) with and without access to a pediatric critical care telemedicine program.

Methods: In this retrospective cohort study, we included pediatric patients aged 18 years and younger admitted directly to the PICU from referring EDs between 2010 and 2014. We compared demographic factors, severity of illness and clinical outcomes among children receiving care in EDs with and without access to pediatric telemedicine, as well as a sub-cohort of children admitted from EDs before and after the implementation of telemedicine.

Results: Five hundred eighty-two patients from 15 EDs with telemedicine and 524 patients from 60 EDs without telemedicine were transferred and admitted to the PICU. Children admitted from EDs using telemedicine were younger (5.6 vs. 6.9 years, $p<0.001$) and less sick (PRISM III score 3.2 vs. 4.0, $p<0.05$) upon admission to the PICU compared to children admitted from EDs without telemedicine. Among transfers from EDs that established telemedicine programs during the study period, children arrived significantly less sick (mean PRISM III scores 1.2 units lower, $p=0.03$) after the implementation of telemedicine (N=43) than before the implementation of telemedicine (N=95). The Observed to Expected (O/E) mortality ratios of post-telemedicine, pre-telemedicine and no-telemedicine cohorts were 0.81 (95% CI, 0.53–1.09), 1.07 (95% CI, 0.53–1.60) and 1.02 (95% CI, 0.71–1.33), respectively.

Conclusions: The implementation of a telemedicine program designed to assist in the care of seriously ill children receiving care in referring EDs was associated with lower illness severity upon admission to the PICU. This study contributes to the body of evidence that pediatric critical care telemedicine programs assist referring EDs in the care of critically ill children and could result in improved clinical outcomes.

INTRODUCTION

Previous research has demonstrated that children transferred and directly admitted to Pediatric Intensive Care Units (PICUs) from referring Emergency Departments (EDs) have higher severity of illness on admission than children admitted directly to the PICU from EDs within the same hospital as the PICU.[13-16] Higher severity of illness is associated with higher morbidity,[15,16,18,19] higher mortality,[13,15,20-22] longer length of hospital stays,[13,18] and higher resource utilization.[13,18,22,23]

The higher severity of illness among children transferred from referring EDs can be partly explained by the lack of pediatric subspecialty expertise, [7,10-12] experience,[7,10] equipment,[7] and infrastructure in EDs[7] located within non-tertiary children's hospitals. Lower annual pediatric volumes and the regionalization of pediatric specialty care make it difficult to maintain the sufficient infrastructure and clinical staff specialized in the care of seriously ill children. Because of this, telemedicine has been increasingly utilized by referring EDs to address disparities in access to pediatric subspecialists.[51] Data from previous research has demonstrated that the use of telemedicine to support the care of seriously ill children in referring EDs results in higher provider and patient satisfaction,[38-41] improved clinical outcomes,[42] fewer medication errors,[11] and higher quality of medical care.[39,43] Pediatric telemedicine consultations can sometimes obviate unnecessary transfers,[42-45] facilitate timely and appropriate stabilization prior to and during the transfer process,[44,45] and may result in lower severity of illness upon admission to the PICU and improved outcomes.

While many telemedicine programs have been implemented in the recent past, few studies have evaluated the impact of these programs on pediatric patients transferred for direct admission to PICUs. The objective of this study was to compare characteristics of and outcomes among seriously ill children admitted to a children's hospital PICU from EDs with and without access to pediatric critical care consultations using telemedicine. Using a sub-cohort of our sample, we also compared characteristics of and outcomes among children transferred to the PICU from referring EDs before and after the implementation of a pediatric critical care telemedicine program. Our hypothesis was that the presence of a telemedicine program would result in more appropriate therapies and improved stabilization of patients such that these children would arrive less sick and have better outcomes than children transferred from EDs without a telemedicine program.

METHODS

Patient Population and Data Source: We analyzed all pediatric patients (<18 years old) admitted to the PICU at the University of California, Davis Children's Hospital directly from a referring ED between 2010 and 2014. Referring EDs are located throughout a 33-county region covering 65,000 square miles, include both urban and rural/underserved areas in Northern California and serve approximately 6 million people. Pediatric patients are transferred from referring EDs to the PICU at the discretion of the referring ED physicians and/or the recommendation of the consulting pediatric critical care physician.

Data were abstracted from the UC Davis Children's Hospital Virtual PICU Performance System (VPS) database, which is part of a national collection of high-quality data elements used for internal and external benchmarking to better understand, evaluate, and improve care and outcomes of critically ill children.[52] All patients admitted to the PICU are entered into the database, which includes patient demographic information, diagnostic data, and the physiologic and laboratory data needed to calculate illness severity.[53] The UC Davis PICU uses the VPSrecalibrated coefficients for the Pediatric Risk of Mortality (PRISM III) as its preferred measure of severity of illness and mortality prediction algorithm.[54] The PRISM III score is a measure of the physiologic stability of a patient during the first 12–24 hours of admission to a PICU, and has been widely used in the literature for risk-adjustment. In this study, we have used the PRISM III score as a proxy for a patient's severity of illness upon presentation to the UC Davis PICU following initial treatment at the referring ED from where they were transferred to the UC Davis PICU.

Telemedicine Overview: The Pediatric Critical Care Telemedicine Program at the UC Davis Children's Hospital was initiated in 2000 and provides telemedicine consultations to approximately 8.6% of the critically ill pediatric patients transferred from participating referring EDs.[37] To request a consultation, a remote ED physician calls a toll-free number and a UC Davis pediatric critical care physician is then paged to initiate the consultation. The telemedicine consultation consists of audiovisual interactive communication involving the patient, parent/guardian, referring ED providers (physician, nurse, respiratory therapist) and the pediatric critical care physician. The telemedicine equipment consists of a pole-mounted turn-key videoconferencing unit (e.g., Polycom or Cisco), a high-resolution monitor and uninterrupted power supply. The video camera is capable of remote control 10× zoom, pan and tilt capabilities.[39] Upon concluding the consultation, and electronic health record note is either electronically transferred or faxed to the referring hospital to be included in the patient's medical records.[37,39]

Outcome Measures: We compared demographic factors, such as age, and other factors known to be associated with severity of illness at PICU admission, including ground transport distance, and day and time of admission. Transport distance is directly proportional to transport time and longer times could result in physiological deterioration and/or improvements prior to PICU admission. Prior research has demonstrated the association of day and time of admission with severity of illness and clinical outcomes.[55,56] Time of admission was categorized as daytime (8 AM–8 PM) or nighttime (8 PM–8 AM). Day of admission was categorized as weekday (Monday–Friday) or weekend (Saturday and Sunday). We also compared clinical parameters, such as illness severity as measured by the PRISM III score, PICU length of stay, mortality, and disposition.

Two separate analyses were conducted. First, we compared factors among all children transferred to the UC Davis PICU from referring EDs with and without access to pediatric telemedicine. Second, among hospitals that obtained access to pediatric telemedicine during the study period, we compared pre-telemedicine factors to post-telemedicine factors. This allowed us to further improve the comparability of telemedicine and non-telemedicine groups by minimizing bias due to unknown hospital-associated factors in our study groups. To evaluate the association between the existence of a telemedicine program in referring EDs and the PICU risk-adjusted mortality after admission, we also compared standardized O/E mortality ratios (ratio of observed number of deaths to number of deaths predicted by the PRISM III score) among non-telemedicine and telemedicine cohorts, as well as the pre-telemedicine and post-telemedicine cohorts.

Statistical Analyses: We performed all statistical analyses by using Stata Statistical Software: Release 13 (StataCorp, College Station, Texas, USA). For baseline univariable comparisons, we used the Student's t-tests for continuous variables and the chi-square test for categorical variables. We performed multivariable linear regression to compare severity of illness among patients transferred from EDs with telemedicine to those transferred from EDs without telemedicine, adjusting for confounders such as age, transport distance, and day and time of admission. To compare PICU admission severity of illness among patient cohorts before and after the implementation of telemedicine at referring EDs, we performed a linear regression analysis and adjusted for clustering at the hospital level using cluster robust standard errors. P-values <0.05 were considered statistically significant. The Institutional Review Board at the University of California, Davis approved this study.

RESULTS

A total of 582 patients were transferred directly to the PICU from 15 EDs with pediatric telemedicine and 524 patients were transferred from 60 EDs without pediatric telemedicine. As shown in Table 1, children transferred from EDs with telemedicine were significantly younger (5.6 vs. 6.9 years, p<0.001) and were transported over a greater distance (72.4 vs. 63.1 miles, p<0.05) when compared to children transferred from EDs without telemedicine. Fewer children transferred from EDs with telemedicine were admitted during nighttime hours (56.0% vs. 63.9%, p<0.05); however, children transferred from EDs with telemedicine had similar rates of admission during the weekend (31.8% vs. 29.2%, p=0.35) compared to children transferred from EDs without telemedicine. In terms of clinical parameters, patients transferred from EDs with telemedicine arrived to the PICU less ill (PRISM III score 3.2 vs. 4.0, p<0.05) compared to patients transferred from EDs without telemedicine (Table 1). We did not find statistically significant differences in lengths of stay (3.1 vs. 3.8 days, p=0.11) and observed mortality (2.4% vs. 4.4%, p=0.07) between children admitted from EDs with telemedicine compared to those admitted from EDs without telemedicine. After adjusting for age, transport distance, and time and day of admission, children admitted from EDs with telemedicine had lower PRISM III scores on presentation than children admitted from EDs without telemedicine (β = –0.74, 95% CI= –1.46 to –0.01, Table 2).

During the study period, four EDs obtained telemedicine capabilities. Among this cohort, there were 95 patients in the pre-telemedicine cohort and 43 in the post-telemedicine cohort. Baseline characteristics of the pre-telemedicine and post-telemedicine patient cohorts are shown in Table 3. In general, findings were consistent with the entire telemedicine versus non-telemedicine cohorts; however, the differences were not statistically significant, including PRISM III scores (3.8 vs. 2.5, p=0.22) and length of stay (4.1 days vs. 2.4 days, p=0.22).

Regression analysis of the sub-cohort demonstrated that patients transferred after the implementation of telemedicine had lower PRISM III scores (β = –1.2 units, p=0.03) than patients transferred before the implementation of telemedicine. The Observed/Expected (O/E) ratios of post-telemedicine, pre-telemedicine, and no-telemedicine cohorts were 0.81 (95% CI, 0.53–1.09), 1.07 (95% CI, 0.53–1.60), and 1.02 (95% CI, 0.71–1.33) respectively. The O/E ratios were not statistically different from one another.

DISCUSSION

In our study, we evaluated the impact of a pediatric critical care telemedicine consultation program for referring EDs on the severity of illness of children arriving to a tertiary care Children's Hospital PICU. We found that children transferred from EDs with telemedicine capabilities were significantly less sick upon arrival to the PICU, suggesting better care and more appropriate stabilization than that of children transferred from EDs without telemedicine capabilities. This finding was consistent even after adjusting for confounders. Among a sub-cohort of children from hospitals that initiated telemedicine during the study period, those transferred from EDs to the PICU during the post-telemedicine period were significantly less sick upon arrival than those transferred from the same EDs during the pre-telemedicine period. We also found that standardized mortality ratios (O/E ratios) were lower than 1.0 for children admitted from EDs with telemedicine and among the post-telemedicine cohort, and higher than 1.0 for children admitted from EDs without telemedicine and among the pre-telemedicine cohort. These findings suggest that access to telemedicine consultations with pediatric critical care specialists during the initial treatment of children in EDs might offer an opportunity to reduce mortality.

Our study adds to the existing body of knowledge about the variation in illness severity among children admitted to PICUs from different hospitals and hospital locations. The finding that children transferred from EDs lacking pediatric expertise are more ill when they arrive at a PICU in a tertiary care children's hospital is in agreement with previous literature.[13-16] Improving the initial care that these children receive in referring EDs could likely improve clinical outcomes and reduce burdens associated with increased morbidity, length of stay, and mortality.[57,58] In the case of children who are not critically ill, appropriate pre-transfer care might also prevent unnecessary and resource-intensive emergency transportation to a distant and possibly overcrowded PICU.[42,44,45,59]

Since the 2006 release of the Institute of Medicine's report,[60] *The Future of Emergency Care in the United States Health System, Emergency Care for Children: Growing Pains,* the medical community has realized that with the regionalization of pediatric emergency services, there are significant disparities in the ability of different EDs to care for seriously ill children.[61] A recent assessment of EDs underscored the association of annual patient volumes with pediatric readiness for day-to-day and disaster care.[6] Readiness was also associated with the presence of physician and nurse pediatric emergency coordinators. Although there have been improvements in pediatric readiness of all EDs over the last decade, there remain opportunities for more EDs to become compliant with national guidelines. Only 12% of California-based hospitals and 10% of all U.S. hospitals have both an ED and PICU to evaluate and manage critically ill children.[5,6] Thus, it is imperative that EDs without 24/7 access to pediatric subspecialists identify solutions to improve pre-transfer care of this extremely vulnerable population.

The majority of children receive emergency medical care in rural, community, and otherwise non-children's hospitals.[6-8] While most EDs provide high quality of care to children, particularly among the most seriously ill, literature suggests that care provided in non-children's hospitals may have lower ratings for quality of care and higher rates of adverse events, such as medication errors.[8,12,62,63] The use of telemedicine to access pediatric expertise has been shown to be well received as a potential solution to increase access to specialty care.[41] It has also been suggested that telemedicine consultations could serve as opportunities for building collaborative professional relationships with more-experienced practitioners at tertiary care children's hospitals, which has implications for workforce recruitment and retention.[41] Hence, in addition to having a potential impact on improving outcomes among children receiving care in the ED, the use of telemedicine may also indirectly improve quality of care by mitigating staffing-related issues common to rural health systems.

Our study has several limitations. First, there may be inherent differences between hospitals and EDs that participate in the telemedicine program and those hospitals that do not participate in the program. The hospitals represented a convenience sample based on their need, interest in participation, and relationship with UC Davis. Second, the sample size for our sub-cohort analysis comparing illness severity in pre-telemedicine and post-telemedicine cohorts is relatively small, which might limit the detection of a true effect of telemedicine in this context.

However, given our relatively short study period and the low volume of critically ill children needing transfer at referring EDs,[37] this analysis still provides useful insight into the clinical impact of telemedicine consultations with PICU-based pediatric subspecialists. Third, our study does not address the possibility that the lower illness severity of children transferred from EDs with telemedicine capabilities may simply be a consequence of transferring children who are less sick. Without detailed information on the therapies and interventions performed in the EDs as a result of the telemedicine consultations, we are unable to directly attribute the lower PRISM III scores on arrival to the PICU to the telemedicine program. However, our claim finds support in prior research showing that pediatric critical care telemedicine programs in EDs were effective in lowering transfer rates of children to facilities providing higher levels of care.[43] Fourth, while the PRISM III scores for the telemedicine cohort are significantly lower, a reduction in 0.74 units corresponds with approximately 1.3% reduction in expected morality, which is not huge but may be clinically significant. Fifth, we considered the intervention in this study to be the telemedicine program, and not the specific consultation modality—so not all patients transferred from EDs with telemedicine received a telemedicine consultation. We conducted our analysis this way because of the selection bias that would be introduced if we considered the non-random mode of consultation to be the intervention. Last, the EDs transferring patients to the PICU during the study period may not be representative of other referring EDs, potentially limiting the generalizability of our findings. Our study conclusions are based on the assumption that all EDs that have access to telemedicine are using them appropriately for patient consultations. However, many EDs might be underutilizing their telemedicine capabilities, particularly just after installation due to limited proficiency and comfort of the staff with the equipment, the change in relationships with consultation providers in the PICU,[41] and the tendency to continue using established methods of obtaining telephone consultations. Thus, our estimates of severity of illness for the post-telemedicine group could be overestimated. However, even if this were not the case, our inference that telemedicine consultations assist in the initial ED care and help lower the severity of illness of children on arrival to the PICU would not change. Hospitals were not randomized to telemedicine installation, so our results could be subject to confounding bias. We tried to minimize this bias by adjusting for all possible confounding variables reported in the previous literature and accounted for clustering by hospital in the secondary analyses.

We measured each patient's severity of illness using the PRISM III score, which is calculated using physiological measures recorded within the first 24 hours of admission into the PICU.[54] While PRISM III estimates the risk of mortality upon admission to the PICU, the score does not account for the illness severity when the child first sought emergency care at the referring ED. Prior treatment and stabilization at the referring ED could temporarily mask severe morbidity and lead to underestimation of the illness severity score upon arrival at the PICU.[13,15,16,43,64] This could possibly introduce a lead-time bias and result in higher O/E ratios; however, the O/E estimates for children admitted from EDs with telemedicine were lower than 1.0.[18]

In conclusion, children transferred from EDs participating in a pediatric critical care telemedicine program arrive to the PICU less sick than those transferred from EDs without access to telemedicine. Studies evaluating the impact of telemedicine at the patient level are needed to provide further evidence that telemedicine consultations improve pre-transfer care.

REFERENCES

1. Odetola FO, Rosenberg AL, Davis MM, et al: Do outcomes vary according to the source of admission to the pediatric intensive care unit? *Pediatr Crit Care Me* 2008; 9(1):20-25.
2. Odetola FO, Davis MM, Cohn LM, et al: Interhospital transfer of critically ill and injured children: an evaluation of transfer patterns, resource utilization, and clinical outcomes. *Journal of hospital medicine* 2009; 4(3):164-170.
3. Gregory CJ, Nasrollahzadeh F, Dharmar M, et al: Comparison of critically ill and injured children transferred from referring hospitals versus in-house admissions. *Pediatrics* 2008; 121(4):E906-E911.
4. Odetola FO, Clark SJ, Gurney JG, et al: Effect of interhospital transfer on resource utilization and outcomes at a tertiary pediatric intensive care unit. *J Crit Care* 2009; 24(3):379-386.
5. Golestanian E, Scruggs JE, Gangnon RE, et al: Effect of interhospital transfer on resource utilization and outcomes at a tertiary care referral center. *Crit Care Med* 2007; 35(6):1470-1476.
6. Odetola FO, Mann NC, Hansen KW, et al: Source of admission and outcomes for critically injured children in the mountain states. *Archives of pediatrics & adolescent medicine* 2010; 164(3):277-282.
7. Combes A, Luyt CE, Trouillet JL, et al: Adverse effect on a referral intensive care unit's performance of accepting patients transferred from another intensive care unit. *Crit Care Med* 2005; 33(4):705-710.
8. Durairaj L, Will JG, Torner JC, et al: Prognostic factors for mortality following interhospital transfers to the medical intensive care unit of a tertiary referral center. *Crit Care Med* 2003; 31(7):1981-1986.
9. Hill AD, Vingilis E, Martin CM, et al: Interhospital transfer of critically ill patients: demographic and outcomes comparison with nontransferred intensive care unit patients. *J Crit Care* 2007; 22(4):290-295.
10. Pollack MM, Patel KM, Ruttimann UE: Pediatric critical care training programs have a positive effect on pediatric intensive care mortality. *Crit Care Med* 1997; 25(10):1637-1642.
11. Tilford JM, Simpson PM, Green JW, et al: Volume-outcome relationships in pediatric intensive care units. *Pediatrics* 2000; 106(2 Pt 1):289-294.
12. Dharmar M, Kuppermann N, Romano PS, et al: Telemedicine consultations and medication errors in rural emergency departments. *Pediatrics* 2013; 132(6):1090-1097.
13. Dharmar M, Marcin JP, Romano PS, et al: Quality of Care of Children in the Emergency Department: Association with Hospital Setting and Physician Training. *J Pediatr-Us* 2008; 153(6):783-789.
14. Athey J, Dean JM, Ball J, et al: Ability of hospitals to care for pediatric emergency patients. *Pediatr Emerg Care* 2001; 17(3):170-174.
15. Uscher-Pines L, Kahn JM: Barriers and facilitators to pediatric emergency telemedicine in the United States. *Telemedicine journal and e-health : the official journal of the American Telemedicine Association* 2014; 20(11):990-996.
16. Yang NH, Dharmar M, Hojman NM, et al: Videoconferencing to reduce stress among hospitalized children. *Pediatrics* 2014; 134(1):e169-175.

17. Dharmar M, Romano PS, Kuppermann N, et al: Impact of Critical Care Telemedicine Consultations on Children in Rural Emergency Departments. *Crit Care Med* 2013; 41(10):2388-2395.
18. Marcin JP, Nesbitt TS, Kallas HJ, et al: Use of telemedicine to provide pediatric critical care inpatient consultations to underserved rural northern California. *J Pediatr-Us* 2004; 144(3):375-380.
19. Ray KN, Demirci JR, Bogen DL, et al: Optimizing Telehealth Strategies for Subspecialty Care: Recommendations from Rural Pediatricians. *Telemedicine journal and e-health : the official journal of the American Telemedicine Association* 2015; 21(8):622-629.
20. Webb CL, Waugh CL, Grigsby J, et al: Impact of Telemedicine on Hospital Transport, Length of Stay, and Medical Outcomes in Infants with Suspected Heart Disease: A Multicenter Study. *J Am Soc Echocardiog* 2013; 26(9):1090-1098.
21. Yang NH, Dharmar M, Kuppermann N, et al: Appropriateness of disposition following telemedicine consultations in rural emergency departments. *Pediatric critical care medicine : a journal of the Society of Critical Care Medicine and the World Federation of Pediatric Intensive and Critical Care Societies* 2015; 16(3):e59-64.
22. LaBarbera JM, Ellenby MS, Bouressa P, et al: The Impact of Telemedicine Intensivist Support and a Pediatric Hospitalist Program on a Community Hospital. *Telemed E-Health* 2013; 19(10):760-766.
23. Heath B, Salerno R, Hopkins A, et al: Pediatric critical care telemedicine in rural underserved emergency departments. *Pediatr Crit Care Me* 2009; 10(5):588-591.
24. Bennett TD, Spaeder MC, Matos RI, et al: Existing data analysis in pediatric critical care research. *Frontiers in pediatrics* 2014; 2:79.
25. J.P.Marcin SLBa: Analysis Outcomes and Quality. In: *Pediatric Critical Care Medicine: Basic Science and Clinical Evidence.* Springer; 2007: 58.
26. Pollack MM, Patel KM, Ruttimann UE: PRISM III: An updated pediatric risk of mortality score. *Crit Care Med* 1996; 24(5):743-752.
27. Hernandez M, Hojman N, Sadorra C, et al: Pediatric Critical Care Telemedicine Program: A Single Institution Review. *Telemedicine journal and e-health : the official journal of the American Telemedicine Association* 2015.
28. Arias Y, Taylor DS, Marcin JP: Association between evening admissions and higher mortality rates in the pediatric intensive care unit. *Pediatrics* 2004; 113(6):E530-E534.
29. Barnett MJ, Kaboli PJ, Sirio CA, et al: Day of the week of intensive care admission and patient outcomes - A multisite regional evaluation. *Med Care* 2002; 40(6):530-539.
30. Yang NH, Dharmar M, Yoo BK, et al: Economic Evaluation of Pediatric Telemedicine Consultations to Rural Emergency Departments. *Med Decis Making* 2015; 35(6):773-783.
31. Marcin JP, Nesbitt TS, Struve S, et al: Financial benefits of a pediatric intensive care unit-based Telemedicine program to a rural adult intensive care unit: Impact of keeping acutely ill and injured children in their local community. *Telemed J E-Health* 2004; 10:S1-S5.
32. Huang DT: Clinical review: Impact of emergency department care on intensive care unit costs. *Crit Care* 2004; 8(6):498-502.
33. Medicine Io: IOM report: The future of emergency care in the United States health system. *Acad Emerg Med* 2006; 13(10):1081-1085.

34. Marcin JP: Telemedicine in the Pediatric Intensive Care Unit. *Pediatr Clin N Am* 2013; 60(3):581-+.
35. Gausche-Hill M, Ely M, Schmuhl P, et al: A National Assessment of Pediatric Readiness of Emergency Departments. *Jama Pediatr* 2015; 169(6):527-534.
36. Remick K, Kaji AH, Olson L, et al: Pediatric Readiness and Facility Verification. *Ann Emerg Med* 2015.
37. Kanter RK: Regional variation in child mortality at hospitals lacking a pediatric intensive care unit. *Crit Care Med* 2002; 30(1):94-99.
38. Marcin JP, Dharmar M, Cho M, et al: Medication errors among acutely ill and injured children treated in rural emergency departments. *Ann Emerg Med* 2007; 50(4):361-367.
39. Odetola FO, Miller WC, Davis MM, et al: The relationship between the location of pediatric intensive care unit facilities and child death from trauma: A county-level ecologic study. *J Pediatr-Us* 2005; 147(1):74-77.
40. Dragsted L, Jorgensen J, Jensen NH, et al: Interhospital comparisons of patient outcome from intensive care: importance of lead-time bias. *Crit Care Med* 1989; 17(5):418-422.

Table 1. Demographic and clinical parameters of pediatric patients transferred from EDs with and without telemedicine

Parameter	No Telemedicine *n* = 524	Telemedicine *n* = 582	*P*
Mean age, years (SD)*	6.9 (5.9)	5.6 (5.7)	<0.001
Mean transport distance, miles (SD)*	63.1 (70.9)	72.4 (69.6)	<0.05
Nighttime admission, *n* (%)*	335 (63.9)	326 (56.0)	<0.05
Weekend admission, *n* (%)	153 (29.2)	185 (31.8)	0.35
Mean PRISM III score (SD)*	4.0 (6.7)	3.2 (5.4)	<0.05
Mean length of PICU stay (SD)	3.8 (9.4)	3.1 (5.5)	0.11
Mortality, *n* (%)	23 (4.4)	14 (2.4)	0.07
PICU Disposition, *n* (%)			0.37
General care floor	297 (56.7)	334 (57.4)	
Home	150 (28.6)	184 (31.6)	
Step-down unit	15 (2.9)	13 (1.2)	
Another ICU	8 (1.5)	9 (1.5)	
Other	54 (10.3)	42 (8.3)	

* *P* <0.05, SD: Standard Deviation

Table 2. Multivariable analysis showing the association between telemedicine EDs and patients' PRISM III score

Parameter	Beta-coefficient	Standard Error	95% Confidence Interval (CI)
ED with telemedicine	–0.74	0.37	–1.47, –0.02
Transport distance, miles	–0.002	0.003	–0.007, 0.003
Age, years	0.07	0.03	0.01, 0.13
Daytime admission	0.68	0.37	–0.06, 1.41
Weekend admission	0.25	0.40	–0.53, 1.02

Table 3. Demographic and clinical parameters of pediatric patients transferred from EDs before and after implementation of a telemedicine program

Parameter	Pre-telemedicine *n* = 95	Post-telemedicine *n* = 43	*P*
Mean age, years (SD)	6.6 (6.0)	4.6 (4.9)	0.06
Nighttime admission, *n* (%)	53 (55.8)	23 (53.5)	0.80
Weekend admission, *n* (%)	24 (25.3)	15 (34.9)	0.51
Mean PRISM III score (SD)	3.8 (5.9)	2.5 (3.5)	0.22
Mean PICU length of stay, days (SD)	4.1 (8.9)	2.4 (2.3)	0.22
Mortality, *n* (%)	4 (4.2)	1 (2.3)	0.58

SD: Standard Deviation

Chapter 2

Appointment Completion in Pediatric Neurology Telemedicine Clinics Serving Underserved Patients

ABSTRACT

Objective: UC Davis Children's Hospital (UCDCH) provides neurology consultations to children both in-person and remotely by telemedicine at outpatient clinics in underserved communities of California. We compared appointment completion between the in-person and telemedicine clinics to determine if telemedicine improves access to care for underserved patients.

Methods: We identified patients scheduled for outpatient care from UCDCH pediatric neurologists between January 1, 2009 and July 31, 2017, in-person and by telemedicine. Demographic and clinical variables were abstracted from electronic medical records. We evaluated the association between consultation modality and visit completion in overall and matched samples using hierarchical multivariable logistic regression.

Results: We analyzed 13,311 in-person appointments by 3,831 patients and 1,158 telemedicine appointments by 381 patients. The average travel time to the site of care was 45.8±52.1 minutes for the in-person cohort and 22.3±22.7 minutes for telemedicine cohort. Telemedicine sites were located at an average travel time of 217.1±114.8 minutes from UCDCH. Telemedicine patients were more likely to have non-private insurance, lower education and lower household income. They had different diagnoses and fewer complex chronic conditions. Telemedicine visits were more likely to be completed than either "cancelled" or missed ("no-show") compared to in-person visits (OR 1.57, 95% CI: 1.34–1.83; OR 1.66, 95% CI: 1.31–2.10 matched on travel time to site of care; OR 2.22, 95% CI: 1.66–2.98 matched on travel time to UCDH).

Conclusions: Children who were scheduled for telemedicine appointments with pediatric neurologists had higher odds of visit completion than children who were scheduled at the urban in-person clinics of an academic, tertiary-care hospital.

INTRODUCTION

Among all medical specialties, neurology has one of the highest shortages of specialists.[24] A recent study estimated that an additional 10% of adult neurologists and 20% of pediatric neurologists are needed to fully meet current clinical needs.[24] This shortage is projected to persist or worsen in the coming decade.[24] For children living in rural communities, access is even more difficult given the regionalization of pediatric subspecialty care to urban areas.[25-27,31] As a result, rural children with neurological disorders and their families frequently travel long distances to obtain needed subspecialty care. Hardships associated with travel—including missed work, missed school, and high transportation costs—often result in patients failing to complete their scheduled medical appointments.[28-31] Inconsistent subspecialty care, in turn, can result in poorer health outcomes, as well as extra visits to the emergency department (ED) or preventable hospitalizations.[32-35]

Real-time telemedicine consultations reduce the time and financial burden of subspecialty visits for rural families, and may thereby improve visit completion rates and pediatric neurologist access in underserved communities.[28,46] UC Davis Children's Hospital (UCDCH) has been providing pediatric neurology services through telemedicine to medically underserved communities in California since 2009. To better understand the impact of this program on access to pediatric neurology care, we compared visit completion between the remote telemedicine clinics and the on-site, in-person clinics. We hypothesized that patients would be equally or more likely to complete appointments scheduled over telemedicine as compared to the appointments scheduled in the in-person clinics, after adjusting for clinical and demographic differences.

METHODS

Telemedicine Visits: Since 2009, the Division of Pediatric Neurology at UCDCH has completed more than 1200 visits with patients in underserved and rural communities over telemedicine. Telemedicine consultations are offered for new and follow-up appointments at 15 remote sites, primarily located in northern California (see Figure 1). Remote clinic staff and primary care providers collect each patient's vitals and history, perform and report a detailed physical exam, and discuss visit recommendations together with the patient and subspecialist. Laboratory test results (such as electroencephalography) and neurological imaging (such as computer tomography or magnetic resonance imaging) are faxed, mailed or shared over picture archiving and communication systems (PACS) to the pediatric neurologist either prior to or during the appointment. Live videoconferencing is conducted over turnkey telemedicine codecs with full UCDCH provider access to remote pan-tilt-zoom capabilities. The pediatric neurologist then documents the consultation note within UCDCH's electronic health record (EHR) system, and this note is either electronically shared or faxed to the remote clinic site.

Study Population: The study population consisted of patients aged 18 years and younger whose registered home addresses were within California, and who completed at least one visit with a UCDCH pediatric neurologist between January 1, 2009 and July 31, 2017 either in-person or over telemedicine. Visits included in the analysis were those scheduled between January 1, 2009 and the date that the patient turned 19 years old or July 31, 2017, whichever occurred first. We did not include patients who were scheduled but never seen.

Data Source and Variables: We abstracted demographic variables (age, sex, and insurance status), patient and telemedicine clinic addresses, dates and completion status of scheduled appointments, and presenting encounter diagnoses from the UCDH EHR system. Sex, medical insurance status and patient addresses were assumed to stay constant throughout the study period and their values were designated as those recorded in the EMR at the time of the data pull. Insurance status was dichotomized into private (commercial employer-based) and non-private, which included public insurance (e.g., Medicaid, managed Medicaid), self-pay, and no insurance. Addresses were geocoded and mapped to U.S. census tracts. Aggregate census tract information was used to assign patients' neighborhood median household income and education level (defined as the proportion of residents with a Bachelor's degree or higher) using the 2016 American Community Survey's 5-year estimates.[65] We categorized the median household income as less than $35,000, $35,000–$45,000, $45,000–$60,000 and more than $60,000. We categorized education level as less than 10%, 10%–15%, 15%–20% and greater than 20% college educated residents. Both variables were categorized into quartiles, which were modified to ensure that the highest and lowest categories included a sufficient number of observations in both comparison groups for analysis. Geocoded addresses were also used to estimate patients' travel times to UCDCH (i.e., the time needed to travel from the patient's home and UCDCH), as well as patients' travel time to the site of care; i.e., the time needed to travel from the patient's home to the remote outpatient clinic for telemedicine visits and UCDCH for the in-person visits. Travel times were estimated assuming vehicle speeds under standard traffic conditions using the *georoute* command in Stata.

ICD-9 codes for the primary presenting diagnosis were used to determine the presence of a pediatric complex chronic condition using a previously validated algorithm.[66] This algorithm flags diagnosis codes corresponding to complex chronic conditions among pediatric patients. The algorithm was developed by clinicians experienced in the care of children with chronic conditions. They defined a complex chronic condition as "any medical condition that can be reasonably expected to last at least 12 months (unless death intervenes) and to involve either several different organ systems or 1 organ system severely enough to require specialty pediatric care and probably some period of hospitalization in a tertiary care center." This algorithm has been widely used in the literature for risk-adjustment and identification of patients who are likely to have higher healthcare resource utilization. We also combined the patients' presenting encounter diagnoses into broad clinical categories for comparison between the cohorts based on the recommendation of our neurologists. For a missing diagnosis code—and corresponding diagnosis category and complex chronic condition status—resulting from a canceled or no-show visit, we used the non-missing values from the patient's previous or following completed appointment, whichever was temporally closer. The primary dependent variable in our analysis was completion of scheduled visits, with cancellations and no-shows considered to be uncompleted visits. The primary independent variable was whether the appointment was scheduled in a telemedicine or in-person clinic.

Statistical Analysis: Simple descriptive statistics were used to characterize study variables. Univariable and bivariable comparisons were conducted using Student's t-tests, Pearson's chi-squared tests and Wilcoxon rank sum tests, as appropriate. The odds of visit completion were estimated using logistic regression with random intercepts for patients to account for patient-level correlations between scheduled appointments. Unconditional multivariable logistic regression models evaluating the odds of completion for visits scheduled over telemedicine compared to those scheduled in-person were adjusted for various potential confounders including patient's age, travel time to site of care, insurance status, median household income, education level, year of visit and the presence of a complex chronic condition. The confounders were chosen for inclusion in the model based on associations observed in the descriptive analysis as well as a-priori, based on our hypothesis. We also evaluated the adjusted visit completion odds ratios for each presenting diagnosis category to determine if visit completion by consultation modality varied by the patient's diagnosis.

To check the robustness of our findings, we also evaluated visit completion in matched subsets of the study population. First, telemedicine and in-person cohorts were matched on travel time to the site of care using a caliper of 5 minutes in a 1:1 ratio (without replacement) to compare cohorts with similar, convenient access to pediatric neurologists. Second, we matched the cohorts on travel time to UCDCH using the same methodology as above to compare visit completion among distant communities with and without telemedicine clinics. We then evaluated the adjusted odds of visit completion in both the time to site of care-matched and time to UCDCH-matched samples. All analyses were carried out using Stata/SE version 15.1 (College Station, Texas). P-values <0.05 were considered to be statistically significant. The Institutional Review Board at UCDH approved this study.

Data availability: Any data not published within the article will be shared in a de-identified form by request from any qualified investigator.

RESULTS

A total of 14,469 appointments scheduled with UCDCH pediatric neurology between January 1, 2009 and July 31, 2017 were included in the study. Of these, 1,158 appointments were scheduled in the telemedicine clinics by 381 patients, and 13,311 appointments were scheduled in the in-person clinic by 3,831 patients. Thirty-nine patients scheduled appointments in both telemedicine and in-person clinics. Telemedicine consultation sites (Figure 1) were located at an average travel time of 217.1 minutes [Standard Deviation (SD) 114.8 minutes] from UCDCH.

As shown in Table 1, patient visits scheduled in the telemedicine and in-person clinics had comparable age and sex distributions. Patients in the telemedicine cohort, however, were less likely to have private insurance compared to patients in the in-person cohort (2.1% vs. 34.5%, p<0.001). The mean travel time to the site of care was 22.3 minutes (SD 22.7 minutes) for the telemedicine cohort and 45.8 minutes (SD 52.1 minutes) for the in-person cohort (p<0.001). In contrast, the travel time to UCDCH (location of the in-person clinic) was 157 minutes (SD 33.2 minutes) for the telemedicine cohort, assuming no change in the number of visits scheduled. Patients in the telemedicine cohort were more likely to live in census tracts with a lower median household income (90.4% vs. 46.3% with income ≤$60,000) and lower education level (69.2% vs. 34.9% with ≤20% college graduates).

In terms of clinical characteristics, children scheduled in the telemedicine clinics were slightly less likely to have a complex chronic condition than those scheduled in the in-person clinics (11.5% vs. 14.2%, p=0.004, Table 1). Seizure disorders and developmental delays were the most common primary presenting diagnoses in both clinics (Table 1). A higher proportion of patients in the telemedicine clinics were seen for seizure disorders, disorders of the muscle and nerve, and genetic and congenital disorders while a higher proportion of in-person clinic patients were seen for developmental delays, headaches, and brain degeneration, damage or injury. Seventy-three percent of telemedicine appointments and 65.1% of in-person appointments were completed as scheduled (p<0.001, Table1).

As shown in Table 2, the bivariable odds of visit completion were higher for telemedicine compared to in-person visits (OR 1.46, 95% CI: 1.27–1.68). Females had lower unadjusted odds of visit completion compared to males (OR: 0.89, 95% CI: 0.82–0.95). Visit completion odds decreased by 7% (95% CI: 3%–11%) with a one-hour increase in travel time to the site of care.

Patients from neighborhoods with higher education (≥15% college graduates) had higher odds of visit completion than patients from neighborhoods with lower education (<10% college graduates).

In the adjusted analysis (Table 3), there were higher odds of visit completion in the telemedicine cohort compared to the in-person cohort (adjusted Odds Ratio, aOR: 1.57, 95% CI: 1.34–1.83). Visit completion was inversely associated with encounter age (2% lower odds for a one-year increase in age, 95% CI: 1%–3%) and travel time to the site of care (6% lower odds for a one-hour increase in travel time, 95% CI: 1%–10%). Visit completion odds were higher for patients residing in neighborhoods with 15%–20% college graduates compared to those with <10% college graduates (aOR: 1.22, 95% CI: 1.03–1.44), when adjusting for other confounders. As shown in Table 4, the adjusted odds of visit completion were significantly higher for the telemedicine cohort compared to the in-person cohort within all major presenting diagnosis categories.

As shown in Table 5, the time to site of care-matched sample comprised of 1,158 visits in each cohort. Seventy-three percent of telemedicine visits and 65.0% of in-person visits were completed in this sample ($p<0.001$) and the adjusted odds of visit completion were higher for the telemedicine cohort compared to the in-person cohort (aOR 1.66, 95% CI: 1.31–2.10). The time to UCDH-matched sample included 598 visits in each cohort. Seventy-three percent of telemedicine visits and 60.7% in-person visits were completed ($p<0.001$). Similar to previous analysis, the adjusted odds of visit completion were higher for the telemedicine cohort (aOR 2.22, 95% CI: 1.66–2.98).

DISCUSSION

In this retrospective analysis, we found that children completed 73% of their scheduled neurology appointments in the telemedicine clinics and 65% of their scheduled appointments in the traditional in-person clinics of a large, academic, tertiary care hospital. Even after adjusting for potential confounders including travel time to the site of care, we found the odds of visit completion to be 57% higher in the telemedicine clinics than the in-person clinics.

Of the 33 counties which comprise UCDCH's service area, 26 do not have a pediatric neurologist,[67] and all 18 pediatric neurologists in this region practice in urban areas.[68] Thus, outpatient pediatric neurology services are an unmet need in the rural and remote areas of this region. Additionally, our study shows that compared to the patients served by in-person clinics, those served by the telemedicine clinics have lower education and household incomes. The combination of poor local access and socioeconomic factors might result in patients' inability to obtain needed neurology care in the traditional in-person clinics and impact their visit completion rates. In our study, we found that the adjusted odds of completion were higher among telemedicine visits compared to in-person visits, even in the time to UCDCH-matched analysis. This shows that providing neurology consultations through telemedicine in distant communities may reduce disparities in visit completion.

Our results of higher visit completion in the telemedicine clinics concur with a previous study of outpatient telemedicine, which reported that psychiatry patients were more likely to complete telemedicine visits than usual care visits.[69] Improvement in visit completion by reducing patients' travel distance has also been demonstrated in community-based satellite clinics.[30] However, we found visit completion to be higher in the telemedicine cohort even after restricting the sample to patients with shorter travel times to the site of care. This sample included all the telemedicine patients who sought neurology care at their local clinics, as well as urban patients who scheduled in-person visits at UCDCH's on-site clinics. This finding shows that factors in addition to travel-related convenience contributed to the higher completion rates of telemedicine appointments. These may include patient and family-centered factors such as familiarity with the remote clinic location, ease of scheduling neurology consultations with the primary care clinic and/or greater accountability on the part of the child's caregivers due to some degree of integration between the primary care and subspecialist services. For example, the need for care coordination tends to be higher for children with epilepsy and seizure disorders because they often have developmental and mental health comorbidities and functional limitations,[47,70] making their treatment more appropriate for team-based care. In the model of care delivery through telemedicine, better care coordination between the child's primary care provider and neurologist facilitates exchange of important health information between the providers and parents, and broadens the primary care provider's knowledge about management of the patient's neurological condition. Moving the system of care closer to a patient's "medical home" may increase parents' comfort and satisfaction with the care process, making them more adherent to their children's scheduled care regimen.[71]

Higher completion of scheduled telemedicine appointments could also be due to greater availability of appointments at local clinic locations. For example, a separate study of in-person pediatric neurology care found that visit completion rate was inversely related to the time between referral and the next available appointment.[72] The analysis of appointment wait times was outside the scope of this study, but we do not expect to find major disparities in appointment wait times between our in-person and telemedicine clinics over the course of the study because both telemedicine and in-person clinics are serviced by the same providers and hospital policy ensured that the burden of wait time did not disproportionately hinder access in one type of clinic compared to the other. Other less expensive ways to improve patient attendance such as enhanced appointment reminder systems, no-show fees and overbooking have demonstrated positive results in some outpatient settings.[73-77] However, these methods have little impact on ameliorating the burden of access for patients residing in remote rural areas.

While this study did not evaluate the quality or outcomes of care provided by telemedicine, other studies have found telemedicine suitable for providing neurologic specialty care[25,78] and demonstrated that the quality of care delivered through telemedicine is comparable to in-person care.[26,47,79-82] In our experience, many neurologic conditions are amenable to medical consultation over telemedicine, especially when a trained clinician is available at the remote site to assist with examinations. We have also noted that continuity of the partnership between the pediatric neurologist and the remote site is key to the seamless operation of the telemedicine clinic. The continued use of telemedicine by some of our sites since the program's inception illustrates that this model of care is agreeable to both patients and providers on a long-term basis.

This study has limitations. First, there are inherent differences between the cohorts because patients were not randomized to telemedicine or in-person visits. However, we attempted to address this limitation by using a multivariable model to adjust for potential confounders. In addition to demographic differences in insurance, income and education levels, there were also clinical differences between the cohorts—such as distribution of primary diagnoses—that could potentially affect care-seeking behavior. However, the adjusted odds of visit completion were significantly higher in the telemedicine clinics for a majority of diagnostic categories including seizures disorders, headaches, developmental delays, disorders affecting the muscle and nerves, and genetic and congenital disorders. This demonstrates that the effect of telemedicine on visit completion is consistent across many diagnoses. A second limitation of our study is that due to its retrospective nature and the use of structured data elements in the EHR, we did not have information on confounders such as the availability of transportation or whether the child's symptoms persisted at the time of the appointment. In addition, there could be differences in important baseline characteristics, such as parents' overall health consciousness, which would affect visit completion. However, we hope that by incorporating patient-level random effects into our model, we have accounted for patients' and families' baseline propensity to complete scheduled appointments. Finally, this study evaluated a subspecialty telemedicine program at a large academic center and these results may not be generalizable to other telemedicine programs, which might vary in delivery models (consultative vs. direct care), populations served (adults vs. children), clinical services offered (primary care vs. subspecialty) and goal targeted (expanded access vs. reduction in clinic wait times). Our evaluation of access to care also focuses on completion of scheduled visits, so does not capture patients who were referred but not scheduled and does not include patients who were scheduled to see pediatric neurologists but failed to successfully complete even a single visit. These measures of access to care were outside the scope of available data for our analysis.

The study also has several strengths. First, our comparison groups were well balanced across age and sex. Second, the multivariable model includes many factors found predictive of appointment non-completion in previous studies, such as travel time to the site of care and socioeconomic factors,[29] and the results of this model appear robust with matched analyses. Lastly, to the best of our knowledge, this study is the first to compare visit completion rates in telemedicine and in-person pediatric neurology clinics and adds to the limited pool of studies evaluating the effectiveness of subspecialty telemedicine care for children.

The low density and urban clustering of pediatric neurologists in UCDCH's service area and nationwide have made it necessary to find ways by which providers can extend services within existing time and resource constraints. Telemedicine is one solution that can improve access by offering greater flexibility to patients and providers. By improving subspecialist availability and enhancing care coordination, telemedicine may reduce disparities in patients' receipt of necessary care and may improve the quality of life for patients and their caregivers in rural and underserved communities.

Figure 1. Telemedicine clinic locations served by UC Davis Children's Hospital's pediatric neurologists

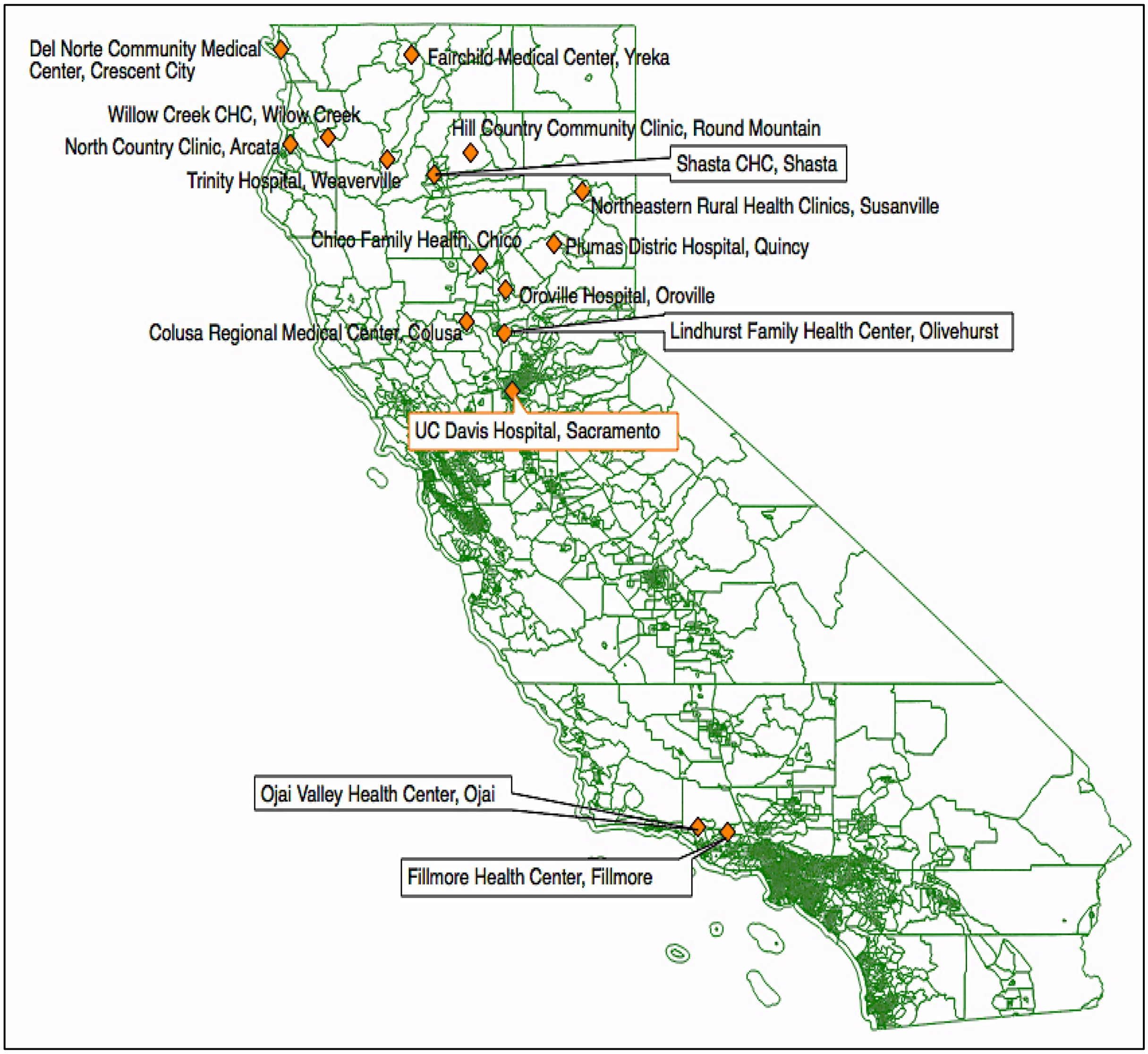

Table 1. Baseline characteristics of the telemedicine and in-person cohorts

Patient characteristics	Telemedicine, N (%) 1,158 (8.0)	In-person, N (%) 13,311 (92.0)	P
Encounter age in years, mean (SD)	8.5 (5.1)	8.3 (5.0)	0.31
Sex, N (%)			
Female	532 (45.9)	6,172 (46.4)	0.78
Male	626 (54.1)	7,139 (55.6)	
Insurance status, N (%)			
Private	24 (2.1)	4,597 (34.5)	<0.001
Non-private (public/self-pay/other)	1,134 (97.9)	8,714 (65.5)	
Time to UCDH in minutes, mean (SD)	157.0 (33.2)	46.4 (52.9)	<0.001
Time to the site of care[1] in minutes, mean (SD)	22.3 (22.7)	45.8 (52.1)	<0.001
Median household income[2] in dollars, N (%)			
<35,000	395 (34.1)	1, 489 (11.2)	<0.001
35-45,000	345 (29.8)	1,956 (14.7)	
45-60,000	307 (26.5)	2,720 (20.4)	
>60,000	111 (9.6)	7,146 (53.7)	
Percent with Bachelor's degree or higher[2], N (%)			
<10%	260 (22.5)	1,256 (9.4)	<0.001
10-15%	298 (25.7)	1,718 (12.9)	
15-20%	243 (21.0)	1,673 (12.6)	
>20%	357 (30.8)	8,664 (65.1)	
Presenting diagnosis, N (%)			
Seizures and suspected seizures	569 (49.1)	5,049 (37.9)	<0.001
Developmental disorders and delays	118 (10.2)	1,912 (14.4)	
Headaches and migraine	53 (4.6)	1,884 (14.2)	
Disorders of muscle and nerve[3]	134 (11.6)	1,336 (10.0)	
Genetic and congenital disorders	73 (6.3)	741 (5.6)	
Brain degeneration, damage or injury	29 (2.5)	580 (4.4)	
Other[4]	65 (5.6)	1,242 (9.3)	
General/non-specific disorders	102 (8.8)	472 (3.6)	
Missing	15 (1.3)	95 (0.7)	
Pediatric complex chronic condition, N (%)			
No	1,010 (87.2)	11,321 (85.1)	0.004
Yes[5]	133 (11.5)	1,895 (14.2)	
Missing	15 (1.3)	95 (0.7)	
Visit completion status, N (%)			
Completed	847 (73.1)	8,664 (65.1)	<0.001
No-show or canceled	311 (26.9)	4,647 (34.9)	

[1]For telemedicine cohort: telemedicine clinic at the primary care provider's office, for in-person cohort: UCDH
[2]In patient's census tract region
[3]Including movement disorders
[4]Including fatigue, sleep, vision, infection, neoplasm, behavioral/mental/social, skin, ear/hearing disorders
[5]Including neuromuscular conditions such as epilepsy/intractable seizures, malignant conditions and congenital/genetic conditions

Table 2. Bivariable/unadjusted odds of visit completion with patient random intercepts

Patient and visit factors	Odds Ratio (95% CI)
Encounter age in years	1.00 (0.98−1.03)
Sex	
Male	REF
Female	0.89 (0.82−0.95)
Insurance status	
Private	REF
Non-private (public/self-pay/other)	0.93 (0.86−1.00)
Travel time to UCDH in hours	1.01 (0.97−1.05)
Time to site of care[1] in hours	0.93 (0.89−0.97)
Median household income[2] in dollars	
<35,000	REF
35−45,000	1.03 (0.90−1.19)
45−60,000	1.02 (0.89−1.15)
>60,000	1.11 (0.99−1.25)
Percent with Bachelor's degree or higher[2]	
<10%	REF
10−15%	1.08 (0.93−1.26)
15−20%	1.18 (1.02−1.38)
>20%	1.15 (1.02−1.30)
Presenting diagnosis, N (%)	
General/non-specific disorders	REF
Seizures and suspected seizures	0.85 (0.71−1.03)
Developmental delays	0.96 (0.78−1.18)
Headaches and migraine	0.82 (0.67−1.01)
Disorders affecting the muscle and nerve[3]	1.05 (0.85−1.29)
Genetic and congenital disorders	0.99 (0.78−1.25)
Brain degeneration/damage/injury	1.11 (0.86−1.43)
Other[4]	1.12 (0.91−1.40)
Pediatric complex chronic condition	
No	REF
Yes[5]	1.04 (0.94−1.16)
Consultation modality	
In−person	REF
Telemedicine	1.46 (1.27−1.68)

[1]For telemedicine cohort: telemedicine clinic at the primary care provider's office, for in-person cohort: UCDH
[2]In patient's census tract region
[3]Including movement disorders
[4]Including fatigue, sleep, vision, infection, neoplasm, behavioral/mental/social, skin, ear/hearing disorders
[5]Including neuromuscular conditions such as epilepsy/intractable seizures, malignant conditions and congenital/genetic conditions

Table 3. Multivariable odds of visit completion with patient random intercepts

Predictor	Adjusted Odds Ratio (95% CI)[1]	P
Consultation modality		
In-person	REF	
Telemedicine	1.57 (1.34−1.83)	<0.001
Encounter age in years	0.98 (0.97−0.99)	<0.001
Travel time to site of care[2] in hours	0.94 (0.90−0.99)	0.01
Insurance status		
Private	REF	
Public/Self-pay/other	0.92 (0.85−1.00)	0.06
Median household income[3] in dollars		
<35,000	REF	
35−45,000	1.02 (0.89−1.19)	0.69
45−60,000	0.99 (0.85−1.14)	0.85
≥60,000	1.11 (0.95−1.30)	0.19
Percent with Bachelor's degree or higher[3]		
<10%	REF	
10−15%	1.09 (0.93−1.28)	0.30
15−20%	1.22 (1.03−1.44)	0.02
>20%	1.13 (0.96−1.32)	0.14
Pediatric complex chronic condition		
No	REF	
Yes[4]	1.02 (0.92−1.13)	0.73

[1]From logistic regression models adjusted for consultation modality, time to site of care (hours), age (years), insurance, median household income, education level, chronic condition presence, year of visit and patient random intercepts
[2]For telemedicine cohort: telemedicine clinic at the primary care provider's office, for in-person cohort: UCDH
[3]In patient's census tract region
[4]Including neuromuscular conditions such as epilepsy/intractable seizures, malignant conditions and congenital/genetic conditions

Table 4. Adjusted odds of visit completion in the telemedicine cohort compared to the in-person cohort

Presenting diagnoses	Adjusted Odds Ratio (95% CI)[2]
Seizures and suspected seizures	1.47 (1.17−1.83)
Developmental delays	1.94 (1.18−3.19)
Headaches and migraine	2.12 (1.08−4.15)
Disorders affecting the muscle and nerves, including movement disorders	2.19 (1.40−3.47)
Genetic and congenital	1.99 (1.10−3.58)
Brain injury, damage or degeneration	1.95 (0.72−5.30)
Other[2]	1.43 (0.76−2.68)
General/non-specific symptoms	0.87 (0.50−1.51)

[1]From logistic regression models adjusted for consultation modality, age (years), travel time to site of care (hours), insurance, median household income, education level, presence of a pediatric complex chronic condition and patient random intercepts

[2]Including fatigue, sleep, vision, infection, neoplasm, behavioral/mental/social, skin, ear/hearing disorders

Table 5. Rates and adjusted odds of visit completion in matched telemedicine and in-person cohorts

Matched factor	N (per cohort)	Visits completed, N (%)			Adjusted Odds Ratio[1] (95% CI)
		Telemedicine	In-person	P	
Time to site of care in minutes[2]	1,158	847 (73.1)	762 (65.0)	<0.001	1.66 (1.31−2.10)
Time to UCDH in minutes[3]	598	436 (72.9)	353 (60.7)	<0.001	2.22 (1.66−2.98)

[1]From logistic regression models adjusted for consultation modality, age (years), insurance, median household income, education level, presence of a pediatric complex chronic condition, year of visit and patient random intercepts

[2]Mean travel time to site of care (minutes): telemedicine cohort= 22.3 (SD 22.7), in-person cohort=25.2 (SD 21.2)

[3]Mean travel time to UCDH (minutes): telemedicine cohort= 153.2 (SD 43.4), in-person cohort=153.1 (SD 44.0)

REFERENCES

1. Dall TM, Storm MV, Chakrabarti R, et al. Supply and demand analysis of the current and future US neurology workforce. Neurology 2013;81(5):470-478.
2. Timpano F, Bonanno L, Bramanti A, et al. Tele-Health and neurology: what is possible? Neurological Sciences 2013;34(12):2263-2270.
3. Davis LE, Coleman J, Harnar J, King MK. Teleneurology: successful delivery of chronic neurologic care to 354 patients living remotely in a rural state. Telemed J E Health 2014;20(5):473-477.
4. Kang PB, Bale JF, Jr., Mintz M, et al. The child neurology clinical workforce in 2015: Report of the AAP/CNS Joint Taskforce. Neurology 2016;87(13):1384-1392.
5. Velasquez SE, Chaves-Carballo E, Nelson EL. Pediatric Teleneurology: A Model of Epilepsy Care for Rural Populations. Pediatr Neurol 2016;64:32-37.
6. Bashiri M, Greenfield LJ, Jr., Oliveto A. Telemedicine Interest for Routine Follow-Up Care Among Neurology Patients in Arkansas. Telemed J E Health 2016;22(6):514-518.
7. Dantas LF, Fleck JL, Cyrino Oliveira FL, Hamacher S. No-shows in appointment scheduling - a systematic literature review. Health Policy 2018;122(4):412-421.
8. McLeod H, Heath G, Cameron E, Debelle G, Cummins C. Introducing consultant outpatient clinics to community settings to improve access to paediatrics: an observational impact study. BMJ Qual Saf 2015;24(6):377-384.
9. Patel AD. Variables associated with emergency department and/or unplanned hospital utilization for children with epilepsy. Epilepsy Behav 2014;31:172-175.
10. Patel AD, Wood EG, Cohen DM. Reduced Emergency Department Utilization by Patients With Epilepsy Using QI Methodology. Pediatrics 2017;139(2).
11. Patel AD, Terry D, Moore JP, et al. Reduction of emergency department visits using an urgent clinic for children with established epilepsy. Neurology-Clinical Practice 2016;6(6):480-486.
12. Nourazari S, Hoch DB, Capawanna S, Sipahi R, Benneyan JC. Can improved specialty access moderate emergency department overuse? Effect of neurology appointment delays on ED visits. Neurology-Clinical Practice 2016;6(6):498-505.
13. Adams JL, George BP, Dorsey ER. Neurologic care ... anytime? Neurology-Clinical Practice 2016;6(6):472-474.
14. American Fact Finder. In: Series. American Fact Finder. Available at: https://factfinder.census.gov/faces/nav/jsf/pages/download_center.xhtml. Accessed August 21, 2017.
15. Feudtner C, Feinstein JA, Zhong W, Hall M, Dai D. Pediatric complex chronic conditions classification system version 2: updated for ICD-10 and complex medical technology dependence and transplantation. BMC Pediatr 2014;14:199.
16. Health Workforce Mapper. In: Series. Health Workforce Mapper. Available at: https://www.ama-assn.org/about-us/health-workforce-mapper. Accessed July 20, 2018.
17. California Medical Service Study Areas (MSSA) Frontier, Rural and Urban Defined Areas. In: Series. California Medical Service Study Areas (MSSA) Frontier, Rural and Urban Defined Areas. Available at: https://www.oshpd.ca.gov/documents/HWDD/GIS/RuralMSSAv3.pdf. Accessed July 20, 2018.

18. Leigh H, Cruz H, Mallios R. Telepsychiatry appointments in a continuing care setting: kept, cancelled and no-shows. J Telemed Telecare 2009;15(6):286-289.
19. Russ SA, Larson K, Halfon N. A national profile of childhood epilepsy and seizure disorder. Pediatrics 2012;129(2):256-264.
20. Rasmusson KA, Hartshorn JC. A comparison of epilepsy patients in a traditional ambulatory clinic and a telemedicine clinic. Epilepsia 2005;46(5):767-770.
21. Herendeen N, Deshpande P. Telemedicine and the patient-centered medical home. Pediatr Ann 2014;43(2):e28-32.
22. Guzek LM, Fadel WF, Golomb MR. A Pilot Study of Reasons and Risk Factors for "No-Shows" in a Pediatric Neurology Clinic. J Child Neurol 2015;30(10):1295-1299.
23. Parikh A, Gupta K, Wilson AC, Fields K, Cosgrove NM, Kostis JB. The effectiveness of outpatient appointment reminder systems in reducing no-show rates. Am J Med 2010;123(6):542-548.
24. Hasvold PE, Wootton R. Use of telephone and SMS reminders to improve attendance at hospital appointments: a systematic review. J Telemed Telecare 2011;17(7):358-364.
25. Reid MW, May FP, Martinez B, et al. Preventing Endoscopy Clinic No-Shows: Prospective Validation of a Predictive Overbooking Model. American Journal of Gastroenterology 2016;111(9):1267-1273.
26. Lesaca T. Assessing the Influence of a No-Show Fee on Patient Compliance at a Cmhc. Administration and Policy in Mental Health and Mental Health Services Research 1995;22(6):629-631.
27. Blaehr EE, Vaeggemose U, Sogaard R. Effectiveness and cost-effectiveness of fining non-attendance at public hospitals: a randomised controlled trial from Danish outpatient clinics. Bmj Open 2018;8(4).
28. Joshi C. Telemedicine in pediatric neurology. Pediatr Neurol 2014;51(2):189-191.
29. Beck CA, Beran DB, Biglan KM, et al. National randomized controlled trial of virtual house calls for Parkinson disease. Neurology 2017;89(11):1152-1161.
30. Muller KI, Alstadhaug KB, Bekkelund SI. Acceptability, Feasibility, and Cost of Telemedicine for Nonacute Headaches: A Randomized Study Comparing Video and Traditional Consultations. J Med Internet Res 2016;18(5):e140.
31. Vierhile A, Tuttle J, Adams H, tenHoopen C, Baylor E. Feasibility of Providing Pediatric Neurology Telemedicine Care to Youth with Headache. J Pediatr Health Care 2018;32(5):500-506.
32. Chua R, Craig J, Esmonde T, Wootton R, Patterson V. Telemedicine for new neurological outpatients: putting a randomized controlled trial in the context of everyday practice. J Telemed Telecare 2002;8(5):270-273.

Chapter 3

Hospital Utilization Among Children in Underserved Communities Served by Pediatric Neurology Telemedicine Clinics

ABSTRACT

Background: Telemedicine is increasingly used to provide outpatient pediatric neurology consultations in underserved communities. While telemedicine clinics have been shown to improve access for underserved children, little is known whether this results in improved outcomes. We aimed to evaluate the impact of neurology telemedicine clinics on patients' utilization of hospital services.

Methods: We identified pediatric patients who obtained outpatient care from a pediatric neurologist at an academic children's hospital between January 1, 2009 and July 31, 2017, in-person and using telemedicine. Demographic and clinical variables were abstracted from electronic medical records. We evaluated the association between telemedicine versus in-person models of outpatient neurology care and patients' utilization of the emergency department and hospitalizations. We analyzed both all-cause and neurological condition-related hospital utilization in overall and matched samples using multivariable negative binomial regression.

Results: The telemedicine and in-person cohorts comprised of 378 patients and 3,791 patients, respectively. The telemedicine cohort was more likely to have non-private insurance, lower education and lower household income. The telemedicine cohort had a lower risk hospital encounters overall with an adjusted incident ratio rate (aIRR) of 0.57 (95% CI: 0.38–0.88) for all-cause encounters and an aIRR of 0.60 (95% CI: 0.36–0.99) for neurological encounters. In

the sample matched on travel time to the neurology clinic, the aIRR was 0.19 (95% CI: 0.04–0.83) for all-cause admissions and 0.14 (95% CI: 0.02–0.82) for neurological admissions.

Conclusion: Children who obtained outpatient neurology care using telemedicine may have lower hospital utilization than children who obtained care at the in-person clinics.

INTRODUCTION

Limited access to outpatient pediatric neurology care can lead to inconsistent management of patients' medical conditions and may result in unplanned hospital encounters including visits to the emergency department or hospital admission.[28-30,32-35,83] Appropriate access to outpatient care is hindered by the shortage of pediatric neurologists across the country. It was recently shown that 20% more pediatric neurologists are needed to fully meet patients' current clinical needs and this shortage is projected to persist or worsen in the coming decade.[24] Confounding these shortages is the fact that pediatric subspecialty care is very regionalized,[25-27] forcing children with neurological disorders and their families living in rural communities to travel long distances to see the nearest pediatric neurologist. Such barriers put these children at greater risk of missing their scheduled medical appointments and receiving less coordinated care.

Real-time telemedicine consultations reduce the time and financial burden of subspecialty appointments for underserved patients.[28,46] UC Davis Children's Hospital (UCDCH) has been providing outpatient pediatric neurology services through telemedicine to primary care provider's offices in underserved communities of California since 2009. In a recent study, we found that these pediatric neurology telemedicine appointments were more likely to be completed rather than cancelled or missed ("no-show") compared to in-person appointments among a cohort of children with similar demographic characteristics and neurological conditions.[84] This and similar studies suggest that outpatient telemedicine models of care can improve access for underserved populations.[28,46,84] However, whether the increased access to care from telemedicine results in a reduction in hospital encounters such as emergency department visits or hospital admissions is not well studied.[26,47-50]

To better understand how outpatient telemedicine models of care might impact patients' utilization of hospital services, we compared the rates of emergency department visits and hospital admissions at UCDCH between similar cohorts of patients who obtained pediatric neurology care at remote telemedicine clinics and those who obtained care at the on-site, in-person outpatient neurology clinics. We hypothesized that patients who received pediatric neurology care using telemedicine in their local community would have comparable or fewer hospital encounters than similar patients who receive pediatric neurology care at UCDCH, after adjusting for clinical and demographic differences.

METHODS

Telemedicine Model: Between 2009 and 2018, the Division of Pediatric Neurology at UCDCH completed more than 1,000 visits with patients in underserved and rural communities over telemedicine. Telemedicine consultations have been offered for new and follow-up appointments at 13 remote sites in northern California. Remote clinic staff and primary care providers collect each patient's vitals and history, perform and report a detailed physical exam, and discuss visit recommendations together with the patient and neurologist. Laboratory test results (such as electroencephalography) and neurological imaging (such as computer tomography or magnetic resonance imaging) are faxed, mailed or shared over picture archiving and communication systems to the pediatric neurologist either prior to or during the appointment. Live videoconferencing is conducted over turnkey telemedicine codecs with full UCDCH provider access to remote pan-tilt-zoom capabilities. The pediatric neurologist then documents the consultation note within UCDCH's Electronic Health Record (EHR) system, and this note is either electronically shared or faxed to the remote clinic site. Patients who attended neurology appointments in these remote telemedicine clinics comprised the telemedicine cohort in this study. Patients who attended appointments in the usual care, in-person clinics located on-site at UCDCH comprised the in-person cohort in the study.

Study Population and Outcome: The study population consisted of patients aged 18 years and younger whose registered home addresses were within UCDCH's 33-county service area in Northern California and who completed at least one clinic visit with a UCDCH pediatric neurologist between January 1, 2009 and July 31, 2017, either over telemedicine or in-person. We did not include patients who were scheduled but never seen. For each included patient, time in the study or the observation period during which they were considered to be "at-risk" for a hospital encounter (emergency department visit or hospital admission) was defined as the time between the patient's first completed neurology appointment and the date when the patient turned 19 years old or July 31, 2017, whichever occurred first. The time in the study for each patient excluded length of stay at the hospital if the child was hospitalized. Hospital encounters that occurred within 24 hours of a previous discharge were not counted as an additional encounter but were instead treated as a single hospital episode. All ED visits were "treat and release" events as ED encounters resulting in admission were treated as a single hospital encounter. Hospital encounters that occurred on the same day as the patient's first completed outpatient appointment were also excluded to ensure that the outcome was subsequent to the start of the patient's observation period in the study.

Data Source and Variables*:* We abstracted all outpatient data (telemedicine and in-person) and hospital encounter data (ED visit or hospital admission) from the UCDCH EHR. Data included demographic variables (age, sex, and insurance status), patient addresses, clinic location data (including the addresses of the telemedicine clinics), hospital encounter type (ED visit or hospital admission), date and time of the hospital encounter, length of stay, and encounter diagnoses from the UCDCH EHR. It is important to note that there are no other hospitals in the communities included in our analyses with pediatric inpatient wards and the necessary clinical staff to care for children with special healthcare needs, including chronic neurological conditions. Further, we limited our analyses to patients in northern California where there were no practicing pediatric neurologists. Therefore, we focused our analysis to justify the assumption that if pediatric patients cared for by UCDCH pediatric neurologists in telemedicine or in-person clinics needed hospital services, they would be transferred or admitted directly to UCDCH.

For each patient, we obtained variables from the neurology outpatient clinic data (telemedicine and in-person), including the total number of outpatient neurology appointments scheduled, proportion of appointments completed and presenting diagnoses. Sex, insurance status and patient addresses were assumed to stay constant throughout the study period and their values were designated as those recorded in the EHR at the time of the data pull. Insurance status was dichotomized into private (commercial employer-based) and non-private, which included public insurance (e.g., Medicaid, managed Medicaid), self-pay, and no insurance. Addresses were geocoded and mapped to U.S. census tracts. Aggregate census tract information was used to assign patients' neighborhood median household income and education level (defined as the proportion of residents with a Bachelor's degree or higher) using the 2016 American Community Survey's 5-year estimates.[65] Geocoded addresses were also used to estimate patients' travel times to their outpatient neurology clinic (i.e., the time needed to travel from the patient's home to the remote telemedicine clinic for the telemedicine cohort and UCDCH for the in-person cohort), as well as patients' travel time to UCDCH (i.e., the time

needed to travel from the patient's home to UCDCH). Travel times were estimated assuming vehicle speeds under standard traffic conditions using the *georoute* command in Stata.
ICD-9 codes for up to five encounter diagnoses were used to determine if the hospital encounter was due to a neurological condition using manual review of codes and applying previously published criteria available in the literature.[85-91] If the hospital encounter was associated with a neurological condition, ICD-9 codes were grouped into clinically relevant categories for comparison between the cohorts. Since a majority of patients who obtained care in the neurology clinics did not have any hospital encounters, we also compared patients' neurology clinic diagnoses between the cohorts. Additionally, ICD-9 diagnoses codes recorded during hospital and/or clinic encounters were used to determine whether the patient had a pediatric complex chronic condition using a previously validated algorithm.[66] This algorithm flags diagnosis codes corresponding to complex chronic conditions among pediatric patients. The algorithm was developed by clinicians experienced in the care of children with chronic conditions. They defined a complex chronic condition as "any medical condition that can be reasonably expected to last at least 12 months (unless death intervenes) and involves either several different organ systems or one organ system severely enough to require specialty pediatric care and probably some period of hospitalization in a tertiary care center." This algorithm has been widely used in the literature for risk-adjustment and identification of patients who are likely to have higher healthcare resource utilization. We determined the chronic condition status of patients who did not have any hospital encounters using their neurology clinic diagnosis codes.

Statistical Analysis: Simple descriptive statistics were used to characterize study variables. Univariable and bivariable comparisons were conducted using Student's t-tests, Pearson's chi-squared tests and Wilcoxon rank sum tests, as appropriate. The primary outcome variable was hospital encounter rate, calculated as the total number of emergency department visits and hospital admissions per patient-year. Rates were calculated for hospital encounters related to any condition (all-cause) and those related to neurological conditions. The primary independent variable was whether the patient received outpatient care in the telemedicine clinics or in the in-person clinic. The telemedicine cohort included patients who scheduled one or more of their outpatient neurology appointments in a telemedicine clinic and the in-person cohort included patients who scheduled all their neurology appointments in the in-person clinics. We compared the rate of all-cause and neurological hospital encounters between the telemedicine and in-person cohorts by estimating the ratio of rates (Incident Rate Ratio, IRR) using negative binomial regression. The negative binomial model allowed us to account for over-dispersion in the total number of hospital encounters and was a better fit for our data than the Poisson model. Patient's time in the study was used as an offset in the model. Models were adjusted for confounders including insurance status, median household income, travel time to UCDCH, presence of a complex chronic condition and outpatient neurology clinic diagnoses. The confounders were chosen for inclusion in the multivariable model based on *a priori* assumptions as well as the associations observed in the descriptive analysis. Outpatient neurology clinic diagnoses were collapsed into three broad categories based on clinical association/affinity for inclusion in the multivariable model. In an additional analysis, we included patient's outpatient neurology appointment completion rate in the adjusted multivariable model to determine how much of the differential risk of having a hospital encounter in the telemedicine cohort was attributable to neurology clinic appointment adherence.

To check the robustness of our findings, we also evaluated adjusted hospital encounter rates in matched subsets of the study population. First, we matched the telemedicine and in-person cohorts on travel time to UCDCH using a caliper of 5 minutes in a 1:1 ratio (without replacement) to compare the rates among cohorts living in communities far from UCDCH. Second, we matched the cohorts on travel time to their neurology clinic (remote telemedicine clinics for the telemedicine cohort and in-person clinics at UCDCH for the in-person cohort) using the same methodology as above to compare hospital encounter rates among cohorts with similar access to outpatient neurology care, with respect to travel time. For this analysis, we limited the limited the outcome to inpatient admissions because ED visits without hospitalization would be more likely to occur at UCDCH among the in-person cohort.

All analyses were carried out using Stata/SE version 15.1 (College Station, Texas). P-values <0.05 were considered to be statistically significant. The Institutional Review Board at UCDCH approved this study.

RESULTS

A total of 4,169 patients with at least one completed appointment with a UC Davis pediatric neurologist between January 1, 2009 and July 31, 2017 were included in the study. Of these, 378 (9.1%) were included in the telemedicine cohort and 3,791 patients were included in the in-person cohort (Table 1). Thirty-nine patients had appointments in both telemedicine and in-person clinics and were included in the telemedicine cohort. Telemedicine consultation sites were located at an average travel time of 195.8 minutes [Standard Deviation (SD) 108.0 minutes] from UCDCH.

As shown in Table 1, patients in the telemedicine cohort were less likely to have private insurance compared to patients in the in-person cohort (2.1% vs. 36.6%, p<0.001). Patients in the telemedicine cohort were also more likely to live in census tracts with a lower median household income [mean 42.6 (SD 12.6) thousand dollars vs. 69.3 (SD 29.6) thousand dollars; p<0.001] and lower education level [mean 17.5% (SD 7.4%) college graduates vs. 31.3% (SD 17.9%) college graduates; p<0.001]. The mean travel time to the outpatient neurology clinic was 20.6 minutes (SD 24.4 minutes) for the telemedicine cohort, and 48.0 minutes (SD 52.4 minutes) for the in-person cohort (p<0.001). In contrast, the travel time to the UCDCH in-person clinic was 156.0 minutes (SD 33.9 minutes) for the telemedicine cohort. The telemedicine cohort had a higher neurology clinic appointment completion rate than the in-person cohort, [81.7% (SD 23.5%) vs. 75.7% (SD 25.4%), p<0.001]. On average, patients in the telemedicine cohort were observed in the study for less time than patients in the in-person cohort [mean 3.6 (SD 2.2) years vs. 4.5 (SD 2.7) years, p<0.001; Table 1]. There were differences in the distribution of neurology clinic diagnoses between the cohorts (p<0.001, Table 1), however, the distributions of patients with complex chronic conditions (Table 1) and neurological hospital diagnoses (Appendix Table 1) were comparable between the two cohorts.

In terms of hospital encounters, 40 (10.6%, Table 1) telemedicine patients had 77 all-cause hospital encounters (Table 2) and 28 (7.4%, Table 1) telemedicine patients had 49 neurological hospital encounters (Table 2). In comparison, 1,024 (27.0%, Table 1) in-person patients had 3,544 all-cause hospital encounters (Table 2) and 473 (12.5%, Table 1) in-person patients had 1,531 neurological hospital encounters (Table 2). Frequencies and rates of hospital encounters for each cohort and encounter type are shown in Table 2.

As shown in Table 3, the bivariable all-cause and neurological hospital encounter rate was lower for patients in the telemedicine cohort compared to patients in the in-person cohort (Incident Risk Ratio, IRR 0.25, 95% CI: 0.18–0.36 for all-cause encounters; IRR 0.35, 95%CI:

0.23–0.54 for neurological encounters). The all-cause hospital encounter rate decreased by 41% (95% CI: 35%-46%) and neurological hospital encounter rate decreased by 32% (95% CI: 24%–40%) for a one-hour increase in travel time to UCDCH. Rates of hospital encounters were higher for patients who had non-private insurance compared to those who had private insurance. Median household income and education level at the census-tract region were inversely associated with hospital encounter rate. Additionally, we found that hospital encounter rate was inversely associated with neurology clinic appointment completion [6% (95% CI: 3%–10%) lower all-cause hospital encounter rate and 10% (95% CI: 6%–14%) lower neurological hospital encounter rate for a 10% increase in the appointment completion rate].

In the adjusted analysis (Table 4), there were lower rates of hospital encounters in the telemedicine cohort compared to the in-person cohort (adjusted IRR, aIRR 0.57, 95% CI: 0.38–0.88 for all-cause encounters; aIRR 0.60, 95% CI: 0.36–0.99 for neurological encounters). Hospital encounter rates were higher for patients with non-private insurance and were inversely associated with travel time to UCDCH [42% (95% CI: 34%–48%) lower all-cause hospital encounter rate and 34% (95% CI: 24%–43%) lower neurological hospital encounter rate for a one-hour increase in travel time). Rates of neurological hospital encounters were higher for patients who had a complex chronic condition (aIRR 1.49, 95% CI: 1.10-2.01). Patients who sought neurology clinic appointments for headaches and other disorders were less likely to have hospital encounters than those who sought appointments for seizures disorders, developmental disorders and cerebral impairment (Table 4).

The rate of all-cause hospital encounters in the multivariable model, additionally adjusted for the percentage of outpatient appointments completed by the patient, was lower among telemedicine patients compared to in-person patients (aIRR 0.59, 95% CI: 0.38–0.90). The rate of neurological hospital encounters was lower, but not statistically significant (aIRR 0.63, 95% CI: 0.38–1.05). Further, completion of outpatient appointments was inversely proportional to the hospital encounter rates [6% (95% CI: 3%–9%) lower all-cause hospital encounter rate and 9% (95% CI: 5%–13%) lower neurological encounter rate for a 10% increase in the outpatient appointments completion rate].

As shown in Appendix Table 2, the time to UCDCH-matched sample comprised of 187 patients in each cohort. Bivariable and adjusted rates of hospital encounters were comparable between the cohorts. The time to neurology clinic-matched sample comprised of 378 patients in each cohort. The adjusted rates of all-cause and neurological hospital admissions were lower among the telemedicine than in-person patients, even after adjusting for insurance status, median household income, time to UCDCH, presence of a complex chronic condition and clinic diagnoses and the (aIRR 0.19, 95% CI: 0.04–0.83 for all-cause admissions; aIRR 0.14, 95% CI: 0.02–0.82 for neurological admissions).

DISCUSSSION

In this retrospective observational study, we found that the rate of all-cause hospital encounters was nearly four times lower among children who received pediatric neurology consultations over telemedicine in their local communities compared to children who received care by travelling to the academic, urban, in-person pediatric neurology clinic (5.7 versus 20.1 per 100 patient-years, respectively; $p<0.001$). We also found that the rates of hospital encounters for neurologic-related reasons were almost twice as low among the telemedicine cohort compared to the in-person cohort (3.7 versus 8.9 per 100 patient-years, respectively; $p<0.001$). Our finding of lower hospital use among the telemedicine cohort remained significant and consistent even after adjusting for insurance status, median household income, travel time to UCDCH, neurology clinic diagnoses and the presence of a complex chronic condition.

Our findings are consistent with previous studies that have found that improving access to outpatient care may prevent avoidable utilization of hospital services. For example, pediatric primary care telemedicine at schools and childcare improved access to care and resulted in a 22% reduction in ED use in the telemedicine cohort compared to the control.[92] Another study found that children receiving telemedicine consults from primary care providers as part of a school-based asthma management program had fewer ED visits than children who did not receive telemedicine consultations.[48] Poor access to outpatient neurology care due to longer than average wait times was associated with a 7-times higher likelihood of an ED visit, and reducing wait times by setting up urgent care clinics was associated with a reduction in seizure-related ED visits for among children.[34,35] In our study, the lower rate of hospital encounters in the telemedicine cohort compared to the in-person cohort is in agreement with these findings. As reported by another study in children, it is possible that outpatient appointments replaced some hospital encounters of the telemedicine cohort, thus shifting the overall medical utilization of patients towards outpatient clinics.[49] However, this was not the case in our study as we did not find that patients seen over telemedicine scheduled a significantly higher number of outpatient appointments compared to the in-person cohort.

The lower rate of hospital use in the telemedicine cohort could be attributed to several factors. For example, the higher completion rate of neurology appointments among this cohort could contribute to obtaining recommended care, resulting in better management of patients' medical conditions, which may reduce hospitalizations. We found a significant but small independent effect of appointment completion on the hospital encounter rate in the adjusted analysis. This suggests that other factors also explain the lower hospital use among the telemedicine cohort. Such factors may include improved care coordination between child's primary care provider and neurologist in the telemedicine clinics, which facilitates exchange of important health information between the providers and parents and broadens the primary care provider's knowledge about management of the patient's neurological condition. The need for care coordination tends to be higher for children with chronic conditions such as epilepsy and seizure disorders because these patients often have developmental and mental health comorbidities and functional limitations,[47,70] making their treatment more appropriate for team-based care. Moving the system of care closer to a patient's "medical home" may increase the quality of the care process, resulting in better outcomes.[71,93-95]

Another explanation for lower hospital use among the telemedicine cohort could be the higher average travel time to UCDCH for patients that use telemedicine compared to patients that normally travel to UCDCH for in-person outpatient care. This is intuitive, as patients who reside further away from UCDCH (i.e. all patients in the telemedicine cohort and a subset of the patients in the in-person cohort) are likely to seek hospital care at their nearest community hospital instead of UCDCH. While our multivariable analysis adjusted for travel time to UCDCH found significantly lower rates of hospital use in the telemedicine cohort, we found lower but not statistically significant rates of hospital use in the telemedicine cohort among the travel time to UCDCH-matched patients. It is possible that the non-significance in the travel time to UCDCH-matched sample was due to the small sample size lacking power to detect a statistically significant difference. Interestingly, we found lower rates of hospital admissions in the telemedicine cohort among patients matched on travel time to their outpatient neurology clinic (telemedicine clinics or in-person clinics at UCDCH).

Our study has a few limitations. First, there are inherent differences between the cohorts because patients were not randomized to telemedicine or in-person clinics. However, we attempted to address this limitation by using a multivariable model to adjust for potential confounders. Second, because we did not have access to patients' medical records from other community hospitals in UCDCH's service area, some patients might have had hospital encounters at other hospitals that were not captured in our data. Thus, hospital rates for patients residing in distant communities could be underestimated in our study. We attempted to address this limitation by matching the cohorts on time to UCDCH (comparable risk of UCDCH hospital use) and restricting our comparison to inpatient admissions among patients matched on time to neurology clinics (comparable access to outpatient neurology care and comparable risk of admissions at UCDCH). Third, patients were able to obtain telemedicine or in-person consultations at neurology clinics throughout the observation period for hospital encounters, thus the outcome did not always temporally follow the exposure. However, in this analysis, our main exposure was the overall model of outpatient care and not the consultation modality for each individual outpatient appointment. Fourth, we were not able to determine whether admissions were planned or unplanned and the results of our study may not extend to patients who were referred but not scheduled, and patients who were scheduled to see pediatric neurologists but failed to successfully complete even a single visit. Fifth, we assumed the risk of UCDCH hospital encounters to be comparable between the matched telemedicine and in-patient cohorts, however, this assumption would need to be supported with data in future studies. Last, this study evaluated a subspecialty telemedicine program at a large academic center and these results may not be generalizable to other telemedicine programs, which might vary in delivery models (consultative vs. direct care), populations served (adults vs. children), clinical services offered (primary care vs. subspecialty) and goal targeted (expanded access vs. reduction in clinic wait times).

In conclusion, we found lower rates of hospital encounters among children who received neurology care in their own communities using telemedicine compared to children who received neurology care in the in-person clinics, even in adjusted analysis and certain matched analyses. By improving subspecialist availability in underserved communities and enhancing care coordination between providers, telemedicine may reduce disparities in patients' receipt of necessary care and optimize their utilization of hospital services. Our study adds to the limited but growing body of research confirming the effectiveness of subspecialty telemedicine care for children in rural communities.

REFERENCES

1. Rimsza ME, Hotaling AJ, Moskowitz WB, et al. The Use of Telemedicine to Address Access and Physician Workforce Shortages. *Pediatrics* 2015;136(1):202-209.
2. Marcin JP, Shaikh U, Steinhorn RH. Addressing health disparities in rural communities using telehealth. *Pediatric Research* 2016;79(1):169-176.
3. Pletcher BA, Rimsza ME, Cull WL, Shipman SA, Shugerman RP, O'Connor KG. Primary care pediatricians' satisfaction with subspecialty care, perceived supply, and barriers to care. *J Pediatr* 2010;156(6):1011-1015 e1011.
4. Lorch SA, Myers S, Carr B. The Regionalization of Pediatric Health Care. *Pediatrics* 2010;126(6):1182-1190.
5. Remick K, Kaji AH, Olson L, et al. Pediatric Readiness and Facility Verification. *Ann Emerg Med* 2015.
6. Gausche-Hill M, Ely M, Schmuhl P, et al. A National Assessment of Pediatric Readiness of Emergency Departments. *Jama Pediatrics* 2015;169(6):527-534.
7. Athey J, Dean JM, Ball J, Wiebe R, Melese-d'Hospital I. Ability of hospitals to care for pediatric emergency patients. *Pediatric Emergency Care* 2001;17(3):170-174.
8. Kanter RK. Regional variation in child mortality at hospitals lacking a pediatric intensive care unit. *Critical Care Medicine* 2002;30(1):94-99.
9. Chamberlain JM, Krug S, Shaw KN. Emergency care for children in the United States. *Health Aff (Millwood)* 2013;32(12):2109-2115.
10. Tilford JM, Simpson PM, Green JW, Lensing S, Fiser DH. Volume-outcome relationships in pediatric intensive care units. *Pediatrics* 2000;106(2):289-294.
11. Dharmar M, Kuppermann N, Romano PS, et al. Telemedicine consultations and medication errors in rural emergency departments. *Pediatrics* 2013;132(6):1090-1097.
12. Dharmar M, Marcin JP, Romano PS, et al. Quality of care of children in the emergency department: association with hospital setting and physician training. *J Pediatr* 2008;153(6):783-789.
13. Odetola FO, Rosenberg AL, Davis MM, Clark SJ, Dechert RE, Shanley TP. Do outcomes vary according to the source of admission to the pediatric intensive care unit? *Pediatric Critical Care Medicine* 2008;9(1):20-25.
14. Odetola FO, Davis MM, Cohn LM, Clark SJ. Interhospital transfer of critically ill and injured children: an evaluation of transfer patterns, resource utilization, and clinical outcomes. *J Hosp Med* 2009;4(3):164-170.
15. Gregory CJ, Nasrollahzadeh F, Dharmar M, Parsapour K, Marcin JP. Comparison of critically ill and injured children transferred from referring hospitals versus in-house admissions. *Pediatrics* 2008;121(4):E906-E911.
16. Odetola FO, Clark SJ, Gurney JG, Dechert RE, Shanley TP, Freed GL. Effect of interhospital transfer on resource utilization and outcomes at a tertiary pediatric intensive care unit. *Journal of Critical Care* 2009;24(3):379-386.
17. Evans JM, Dayal P, Hallam DL, et al. Illness Severity of Children Admitted to the PICU From Referring Emergency Departments. *Hosp Pediatr* 2018;8(7):404-409.
18. Golestanian E, Scruggs JE, Gangnon RE, Mak RP, Wood KE. Effect of interhospital transfer on resource utilization and outcomes at a tertiary care referral center. *Crit Care Med* 2007;35(6):1470-1476.

19. Odetola FO, Mann NC, Hansen KW, Patrick S, Bratton SL. Source of admission and outcomes for critically injured children in the mountain states. *Arch Pediatr Adolesc Med* 2010;164(3):277-282.
20. Combes A, Luyt CE, Trouillet JL, Chastre J, Gibert C. Adverse effect on a referral intensive care unit's performance of accepting patients transferred from another intensive care unit. *Crit Care Med* 2005;33(4):705-710.
21. Durairaj L, Will JG, Torner JC, Doebbeling BN. Prognostic factors for mortality following interhospital transfers to the medical intensive care unit of a tertiary referral center. *Critical Care Medicine* 2003;31(7):1981-1986.
22. Hill AD, Vingilis E, Martin CM, Hartford K, Speechley KN. Interhospital transfer of critically ill patients: demographic and outcomes comparison with nontransferred intensive care unit patients. *J Crit Care* 2007;22(4):290-295.
23. Pollack MM, Patel KM, Ruttimann UE. Pediatric critical care training programs have a positive effect on pediatric intensive care mortality. *Critical Care Medicine* 1997;25(10):1637-1642.
24. Dall TM, Storm MV, Chakrabarti R, et al. Supply and demand analysis of the current and future US neurology workforce. *Neurology* 2013;81(5):470-478.
25. Timpano F, Bonanno L, Bramanti A, et al. Tele-Health and neurology: what is possible? *Neurological Sciences* 2013;34(12):2263-2270.
26. Davis LE, Coleman J, Harnar J, King MK. Teleneurology: successful delivery of chronic neurologic care to 354 patients living remotely in a rural state. *Telemed J E Health* 2014;20(5):473-477.
27. Kang PB, Bale JF, Jr., Mintz M, et al. The child neurology clinical workforce in 2015: Report of the AAP/CNS Joint Taskforce. *Neurology* 2016;87(13):1384-1392.
28. Bashiri M, Greenfield LJ, Jr., Oliveto A. Telemedicine Interest for Routine Follow-Up Care Among Neurology Patients in Arkansas. *Telemed J E Health* 2016;22(6):514-518.
29. Dantas LF, Fleck JL, Cyrino Oliveira FL, Hamacher S. No-shows in appointment scheduling - a systematic literature review. *Health Policy* 2018;122(4):412-421.
30. McLeod H, Heath G, Cameron E, Debelle G, Cummins C. Introducing consultant outpatient clinics to community settings to improve access to paediatrics: an observational impact study. *BMJ Qual Saf* 2015;24(6):377-384.
31. Velasquez SE, Chaves-Carballo E, Nelson EL. Pediatric Teleneurology: A Model of Epilepsy Care for Rural Populations. *Pediatr Neurol* 2016;64:32-37.
32. Patel AD. Variables associated with emergency department and/or unplanned hospital utilization for children with epilepsy. *Epilepsy Behav* 2014;31:172-175.
33. Patel AD, Wood EG, Cohen DM. Reduced Emergency Department Utilization by Patients With Epilepsy Using QI Methodology. *Pediatrics* 2017;139(2).
34. Patel AD, Terry D, Moore JP, et al. Reduction of emergency department visits using an urgent clinic for children with established epilepsy. *Neurology-Clinical Practice* 2016;6(6):480-486.
35. Nourazari S, Hoch DB, Capawanna S, Sipahi R, Benneyan JC. Can improved specialty access moderate emergency department overuse? Effect of neurology appointment delays on ED visits. *Neurology-Clinical Practice* 2016;6(6):498-505.
36. UC Davis Pediatric Telemedicine Program. UC Davis Children's Hospital 2018. Available at:

https://health.ucdavis.edu/children/clinical_services/pediatric_telemedicine/index.html. Accessed December 14, 2018.
37. Hernandez M, Hojman N, Sadorra C, et al. Pediatric Critical Care Telemedicine Program: A Single Institution Review. *Telemed J E Health* 2015.
38. Yang NH, Dharmar M, Hojman NM, et al. Videoconferencing to reduce stress among hospitalized children. *Pediatrics* 2014;134(1):e169-175.
39. Dharmar M, Romano PS, Kuppermann N, et al. Impact of Critical Care Telemedicine Consultations on Children in Rural Emergency Departments. *Critical Care Medicine* 2013;41(10):2388-2395.
40. 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. *Journal of Pediatrics* 2004;144(3):375-380.
41. Ray KN, Demirci JR, Bogen DL, Mehrotra A, Miller E. Optimizing Telehealth Strategies for Subspecialty Care: Recommendations from Rural Pediatricians. *Telemed J E Health* 2015;21(8):622-629.
42. Webb CL, Waugh CL, Grigsby J, et al. Impact of Telemedicine on Hospital Transport, Length of Stay, and Medical Outcomes in Infants with Suspected Heart Disease: A Multicenter Study. *Journal of the American Society of Echocardiography* 2013;26(9):1090-1098.
43. Yang NH, Dharmar M, Kuppermann N, et al. Appropriateness of disposition following telemedicine consultations in rural emergency departments. *Pediatr Crit Care Med* 2015;16(3):e59-64.
44. LaBarbera JM, Ellenby MS, Bouressa P, Burrell J, Flori HR, Marcin JP. The Impact of Telemedicine Intensivist Support and a Pediatric Hospitalist Program on a Community Hospital. *Telemedicine and E-Health* 2013;19(10):760-766.
45. Heath B, Salerno R, Hopkins A, Hertzig J, Caputo M. Pediatric critical care telemedicine in rural underserved emergency departments. *Pediatric Critical Care Medicine* 2009;10(5):588-591.
46. Adams JL, George BP, Dorsey ER. Neurologic care ... anytime? *Neurology-Clinical Practice* 2016;6(6):472-474.
47. Rasmusson KA, Hartshorn JC. A comparison of epilepsy patients in a traditional ambulatory clinic and a telemedicine clinic. *Epilepsia* 2005;46(5):767-770.
48. Halterman JS, Fagnano M, Tajon RS, et al. Effect of the School-Based Telemedicine Enhanced Asthma Management (SB-TEAM) Program on Asthma Morbidity: A Randomized Clinical Trial. *JAMA Pediatr* 2018:e174938.
49. McConnochie KM, Wood NE, Herendeen NE, et al. Acute illness care patterns change with use of telemedicine. *Pediatrics* 2009;123(6):e989-995.
50. Guttmann-Bauman I, Kono J, Lin AL, Ramsey KL, Boston BA. Use of Telehealth Videoconferencing in Pediatric Type 1 Diabetes in Oregon. *Telemedicine and E-Health* 2018;24(1):86-88.
51. Uscher-Pines L, Kahn JM. Barriers and facilitators to pediatric emergency telemedicine in the United States. *Telemed J E Health* 2014;20(11):990-996.
52. Bennett TD, Spaeder MC, Matos RI, et al. Existing data analysis in pediatric critical care research. *Front Pediatr* 2014;2:79.
53. J.P.Marcin SLBa. Analysis Outcomes and Quality. *Pediatric Critical Care Medicine: Basic Science and Clinical Evidence*: Springer; 2007:58.

54. Pollack MM, Patel KM, Ruttimann UE. PRISM III: An updated pediatric risk of mortality score. *Critical Care Medicine* 1996;24(5):743-752.
55. Arias Y, Taylor DS, Marcin JP. Association between evening admissions and higher mortality rates in the pediatric intensive care unit. *Pediatrics* 2004;113(6):E530-E534.
56. Barnett MJ, Kaboli PJ, Sirio CA, Rosenthal GE. Day of the week of intensive care admission and patient outcomes - A multisite regional evaluation. *Medical Care* 2002;40(6):530-539.
57. Yang NH, Dharmar M, Yoo BK, et al. Economic Evaluation of Pediatric Telemedicine Consultations to Rural Emergency Departments. *Medical Decision Making* 2015;35(6):773-783.
58. Marcin JP, Nesbitt TS, Struve S, Traugott C, Dimand RJ. Financial benefits of a pediatric intensive care unit-based Telemedicine program to a rural adult intensive care unit: Impact of keeping acutely ill and injured children in their local community. *Telemedicine Journal and E-Health* 2004;10:S1-S5.
59. Huang DT. Clinical review: Impact of emergency department care on intensive care unit costs. *Critical Care* 2004;8(6):498-502.
60. Medicine Io. IOM report: The future of emergency care in the United States health system. *Academic Emergency Medicine* 2006;13(10):1081-1085.
61. Marcin JP. Telemedicine in the Pediatric Intensive Care Unit. *Pediatric Clinics of North America* 2013;60(3):581-+.
62. Marcin JP, Dharmar M, Cho M, et al. Medication errors among acutely ill and injured children treated in rural emergency departments. *Annals of Emergency Medicine* 2007;50(4):361-367.
63. Odetola FO, Miller WC, Davis MM, Bhatton SL. The relationship between the location of pediatric intensive care unit facilities and child death from trauma: A county-level ecologic study. *Journal of Pediatrics* 2005;147(1):74-77.
64. Dragsted L, Jorgensen J, Jensen NH, et al. Interhospital comparisons of patient outcome from intensive care: importance of lead-time bias. *Crit Care Med* 1989;17(5):418-422.
65. Bator EX, Gleason JM, Lorenzo AJ, et al. The burden of attending a pediatric surgical clinic and family preferences toward telemedicine. *J Pediatr Surg* 2015;50(10):1776-1782.
66. Feudtner C, Feinstein JA, Zhong W, Hall M, Dai D. Pediatric complex chronic conditions classification system version 2: updated for ICD-10 and complex medical technology dependence and transplantation. *BMC Pediatr* 2014;14:199.
67. Health Workforce Mapper. American Medical Association. *American Medical Association*. Available at: https://www.ama-assn.org/about-us/health-workforce-mapper. Accessed July 20, 2018.
68. California Medical Service Study Areas (MSSA) Frontier, Rural and Urban Defined Areas. Office of Statewide Planning and Development. *Office of Statewide Planning and Development*. Available at: https://www.oshpd.ca.gov/documents/HWDD/GIS/RuralMSSAv3.pdf. Accessed July 20, 2018.
69. Leigh H, Cruz H, Mallios R. Telepsychiatry appointments in a continuing care setting: kept, cancelled and no-shows. *J Telemed Telecare* 2009;15(6):286-289.
70. Russ SA, Larson K, Halfon N. A national profile of childhood epilepsy and seizure disorder. *Pediatrics* 2012;129(2):256-264.

71. Herendeen N, Deshpande P. Telemedicine and the patient-centered medical home. *Pediatr Ann* 2014;43(2):e28-32.
72. Guzek LM, Fadel WF, Golomb MR. A Pilot Study of Reasons and Risk Factors for "No-Shows" in a Pediatric Neurology Clinic. *J Child Neurol* 2015;30(10):1295-1299.
73. Parikh A, Gupta K, Wilson AC, Fields K, Cosgrove NM, Kostis JB. The effectiveness of outpatient appointment reminder systems in reducing no-show rates. *Am J Med* 2010;123(6):542-548.
74. Hasvold PE, Wootton R. Use of telephone and SMS reminders to improve attendance at hospital appointments: a systematic review. *J Telemed Telecare* 2011;17(7):358-364.
75. Reid MW, May FP, Martinez B, et al. Preventing Endoscopy Clinic No-Shows: Prospective Validation of a Predictive Overbooking Model. *American Journal of Gastroenterology* 2016;111(9):1267-1273.
76. Lesaca T. Assessing the Influence of a No-Show Fee on Patient Compliance at a Cmhc. *Administration and Policy in Mental Health and Mental Health Services Research* 1995;22(6):629-631.
77. Blaehr EE, Vaeggemose U, Sogaard R. Effectiveness and cost-effectiveness of fining non-attendance at public hospitals: a randomised controlled trial from Danish outpatient clinics. *Bmj Open* 2018;8(4).
78. Joshi C. Telemedicine in pediatric neurology. *Pediatr Neurol* 2014;51(2):189-191.
79. Beck CA, Beran DB, Biglan KM, et al. National randomized controlled trial of virtual house calls for Parkinson disease. *Neurology* 2017;89(11):1152-1161.
80. Muller KI, Alstadhaug KB, Bekkelund SI. Acceptability, Feasibility, and Cost of Telemedicine for Nonacute Headaches: A Randomized Study Comparing Video and Traditional Consultations. *J Med Internet Res* 2016;18(5):e140.
81. Vierhile A, Tuttle J, Adams H, tenHoopen C, Baylor E. Feasibility of Providing Pediatric Neurology Telemedicine Care to Youth with Headache. *J Pediatr Health Care* 2018;32(5):500-506.
82. Chua R, Craig J, Esmonde T, Wootton R, Patterson V. Telemedicine for new neurological outpatients: putting a randomized controlled trial in the context of everyday practice. *J Telemed Telecare* 2002;8(5):270-273.
83. Willis AW, Schootman M, Tran R, et al. Neurologist-associated reduction in PD-related hospitalizations and health care expenditures. *Neurology* 2012;79(17):1774-1780.
84. Dayal P, Chang CH, Benko WS, et al. Appointment Completion In Pediatric Neurology Telemedicine Clinics Serving Underserved Patients. University of California Davis Health; 2018.
85. Moreau JF, Fink EL, Hartman ME, et al. Hospitalizations of children with neurologic disorders in the United States. *Pediatr Crit Care Med* 2013;14(8):801-810.
86. Berry JG, Poduri A, Bonkowsky JL, et al. Trends in resource utilization by children with neurological impairment in the United States inpatient health care system: a repeat cross-sectional study. *PLoS Med* 2012;9(1):e1001158.
87. St Germaine-Smith C, Metcalfe A, Pringsheim T, et al. Recommendations for optimal ICD codes to study neurologic conditions: a systematic review. *Neurology* 2012;79(10):1049-1055.
88. ICD-9-CM to ICD-10-CM Codes for Neurology. Diagnostic Services. *Quest Diagnostics*. 2015. Available at: https://www.questdiagnostics.com/dms/Documents/Other/CPT-2015/ICD_9-10_Codes_for_Neurology-MI4958.pdf. Accessed October 20, 2018.

89. ICD-9 to ICD-10 Conversion Commonly Used Neurologic Diagnosis. Complete Practice Resources. *American Academy of Neurology*. Available at: https://www.aan.com/siteassets/home-page/tools-and-resources/practicing-neurologist--administrators/billing-and-coding/icd-10-cm/16icd10aancrosswalk_tr.pdf. Accessed October 20, 2018.
90. Neurology Top Diagnosis Codes (Crosswalk). *Wellstar*. Available at: https://www.wellstar.org/about-us/icd-10/documents/top_diagnosis_codes_(crosswalks)/neurology top diagnosis codes (crosswalk).pdf. Accessed October 20, 2018.
91. ICD-9 to ICD-10 Conversion of Epilepsy. *American Academy of Neurology*. Available at: https://www.aan.com/siteassets/home-page/tools-and-resources/practicing-neurologist--administrators/billing-and-coding/icd-10-cm/16aanepilepsycrosswalk_tr.pdf. Accessed October 20, 2018.
92. Ronis SD, McConnochie KM, Wang H, Wood NE. Urban Telemedicine Enables Equity in Access to Acute Illness Care. *Telemed J E Health* 2017;23(2):105-112.
93. Mosquera RA, Avritscher EB, Samuels CL, et al. Effect of an enhanced medical home on serious illness and cost of care among high-risk children with chronic illness: a randomized clinical trial. *JAMA* 2014;312(24):2640-2648.
94. Burke R, Liptak GS, Council on Children with D. Providing a primary care medical home for children and youth with spina bifida. *Pediatrics* 2011;128(6):e1645-1657.
95. Greenberg JO, Barnett ML, Spinks MA, Dudley JC, Frolkis JP. The "medical neighborhood": integrating primary and specialty care for ambulatory patients. *JAMA Intern Med* 2014;174(3):454-457.

Table 1. Distribution of baseline characteristics among telemedicine and in-person cohorts

Patient characteristics	Telemedicine, N (%) 378 (9.1)	In-person, N (%) 3,791 (90.9)	P
Age at first encounter in years, mean (SD)	7.4 (5.4)	7.8 (5.1)	0.16
Sex, N (%)			
Female	167 (44.2)	1,701 (44.9)	0.80
Male	211 (55.8)	2,090 (55.1)	
Insurance, N (%)			
Private	8 (2.1)	1,387 (36.6)	<0.001
Non-private (public/self-pay/other)	370 (97.9)	2,404 (63.4)	
Median household income[1] in 1,000 dollars, mean (SD)	42.6 (12.6)	69.3 (29.6)	<0.001
Percent with Bachelor's degree or higher,[1] mean (SD)	17.5 (7.4)	31.3 (17.9)	<0.001
Travel time to neurology clinic in minutes, mean (SD)	20.6 (24.4)	48.0 (52.4)	<0.001
Travel time to UCDCH in minutes, mean (SD)	156.0 (33.9)	48.0 (52.4)	<0.001
Percent of clinic appointments completed, mean (SD)	81.7 (23.5)	75.7 (25.4)	<0.001
Time in study per patient in years			
Mean (SD)	3.6 (2.2)	4.5 (2.7)	<0.001
Median (Q1, Q3)	3.1 (1.8, 5.3)	4.6 (2.2, 7.0)	
Patients with a complex chronic condition, N (%)			
No	317 (83.9)	3,290 (88.8)	
Yes	52 (13.8)	446 (11.8)	0.18
Missing	9 (2.4)	55 (1.5)	
Neurology clinic diagnosis, N (%)			
Seizures and suspected seizures	137 (36.2)	1,120 (29.5)	
Developmental disorders	47 (12.4)	594 (15.7)	
Headaches and migraine	25 (6.6)	615 (16.2)	
Disorders of muscle and nerve[2]	48 (12.7)	453 (12.0)	
Genetic and congenital disorders	29 (7.7)	192 (5.1)	<0.001
Cerebral degeneration, damage or injury	13 (3.4)	160 (4.2)	
Other[3]	33 (8.7)	419 (11.1)	
General/non-specific	37 (9.8)	173 (4.5)	
Missing	9 (2.4)	65 (1.7)	
Patients with ≥1 all-cause hospital encounters, N (%)	40 (10.6)	1,024 (27.0)	<0.001
Patients with ≥1 neurological hospital encounters, N (%)	28 (7.4)	473 (12.5)	0.004

[1]In patient's census tract region
[2]Including movement disorders
[3]Including fatigue, sleep, vision, infection, neoplasm, behavioral/mental/social, skin, ear/hearing disorders

Table 2. Hospital encounter frequencies and rates by cohort

Hospital encounter type	Telemedicine		In-person	
	N	Rate (95% CI)[1,2]	N	Rate (95% CI)[1,3]
All-cause encounters	77	5.7 (3.5−8.0)	3,455	20.1 (18.1−22.1)
ED visits	9	0.7 (0.0−1.4)	1,966	11.4 (10.3−12.6)
Hospital admissions	68	5.1 (2.9−7.2)	1,489	8.7 (7.5−9.8)
Neurological encounters	49	3.7 (2.0−5.3)	1,531	8.9 (7.8−10.0)

[1]Number of encounters per 100 patient-years
[2]Total 1,341.8 patient-years in the cohort
[3]Total 17,205.6 patient-years in the cohort

Table 3. Bivariable/unadjusted association of hospital encounter rate with patient factors

Patient factors	All-cause encounters IRR[1] (95% CI)	Neurological encounters IRR[1] (95% CI)
Cohort		
In-person	REF	
Telemedicine	0.25 (0.18−0.36)	0.35 (0.23−0.54)
Age at first encounter in years	1.00 (0.98−1.01)	1.01 (0.99−1.03)
Sex, N (%)		
Female	REF	REF
Male	1.14 (0.96−1.35)	1.02 (0.83−1.26)
Insurance, N (%)		
Private	REF	REF
Non-private (public/self-pay/other)	1.36 (1.14−1.63)	1.51 (1.20−1.90)
Travel time to neurology clinic in hours	0.65 (0.58−0.72)	0.75 (0.64−0.85)
Travel time to UCDCH in hours	0.59 (0.54−0.65)	0.68 (0.60−0.76)
Median household income[2] (per 10,000 dollars)	0.90 (0.88−0.93)	0.88 (0.85−0.92)
Bachelor's degree or higher[2] (per 10% college graduates)	0.85 (0.81−0.89)	0.80 (0.75−0.84)
Neurology clinic appointments completed, per 10%	0.94 (0.90−0.97)	0.90 (0.86−0.94)
Presence of a complex chronic condition		
No	REF	REF
Yes	1.16 (0.90−1.51)	1.61 (1.19−2.20)
Neurology clinic diagnosis category		
Seizures, developmental disorders and cerebral degeneration/damage/injury	REF	REF
Disorders of the muscle and nerve, genetic and congenital disorders	0.86 (0.68−1.08)	0.72 (0.54−0.95)
Headaches and other disorders[3]	0.53 (0.43−0.64)	0.35 (0.27−0.44)

[1]Incident Rate Ratio (IRR) from negative binomial regression with patient's time in the study (years) as an offset
[2]In patient's census tract region
[3]Including migraine, fatigue, sleep, vision, infection, neoplasm, behavioral/mental/social, skin, ear/hearing disorders and general symptoms

Table 4. Multivariable model showing the association of hospital encounter rate with patient factors

Predictor	All-cause encounters aIRR[1] (95% CI)	Neurological encounters[1] aIRR[1] (95% CI)
Cohort		
In-person	REF	
Telemedicine	0.57 (0.38−0.88)	0.60 (0.36−0.99)
Insurance status		
Private	REF	REF
Non-private (public/self-pay/other)	1.08 (0.89−1.31)	1.16 (0.91−1.46)
Median household income[2] (per 10,000 dollars)	0.89 (0.87−0.92)	0.88 (0.84−0.91)
Travel time to UCDCH in hours	0.58 (0.52−0.66)	0.66 (0.57−0.76)
Pediatric complex chronic condition		
No	REF	REF
Yes	1.14 (0.88−1.48)	1.49 (1.10−2.01)
Neurology clinic diagnosis category		
Seizures, developmental disorders and cerebral degeneration/damage/injury	REF	REF
Disorders of the muscle and nerve, genetic and congenital disorders	0.93 (0.74−1.16)	0.75 (0.57−0.99)
Headaches and other disorders[3]	0.55 (0.45−0.67)	0.37 (0.29−0.48)

[1]Adjusted Incident Rate Ratio (aIRR) from negative binomial regression with patient's time in the study (years) as an offset
[2]In patient's census tract region
[3]Including migraine, fatigue, sleep, vision, infection, neoplasm, behavioral/mental/social, skin, ear/hearing disorders and general symptoms

APPENDIX

Appendix Table 1. Comparison of diagnosis categories among neurological hospital encounters[1]

Neurological diagnosis category	Total, N (%)	Telemedicine cohort, N (%)	In-person cohort, N (%)
Seizures and suspected seizures	768 (48.6)	29 (59.2)	739 (48.3)
Developmental delays and behavioral/mental/social disorders	190 (12.0)	7 (14.3)	183 (12.0)
Other[2]	178 (11.3)	3 (6.1)	175 (11.4)
Disorders affecting the muscle and nerves, including movement disorders	150 (9.5)	5 (10.2)	145 (9.5)
Cerebral degeneration and inflammation, spinal cord inflammation & other brain disorders	121 (7.7)	2 (4.1)	119 (7.8)
Headaches and migraines	99 (6.3)	2 (4.1)	97 (6.3)
Intracranial/cerebral/spinal cord injury or damage	74 (4.7)	1 (2.0)	73 (4.8)
Total	1,580 (100)	49 (100)	1,531 (100)

[1]Overall p=0.60

[2]Including eye, ear, sleep, head & neck, neuroendocrine, metabolic, nutritional, neoplasm, device-related complications and genetic/congenital disorders

Appendix Table 2. Comparison of hospital encounter frequencies and rates in matched telemedicine and in-person patient cohorts

Statistic	Matched factor			
	Time to UCDCH in minutes[1]		Time outpatient neurology clinic in minutes[2,3]	
	Telemedicine (N=187)	In-person (N=187)	Telemedicine (N=378)	In-person (N=378)
All-cause encounters, N	52	53	68	369
Neurological encounters, N	34	29	47	211
Total person-years in cohort, mean (SD)	744.3 (31.1)	598.2 (37.7)	1,341.8 (42.2)	1,801.2 (51.4)
Hospital encounter rate ratio (95% CI)				
All-cause encounters	0.59 (0.27−1.29)	REF	0.22 (0.13−0.37)	REF
Neurological encounters	0.70 (0.31−1.55)	REF	0.26 (0.14−0.47)	REF
Adjusted hospital encounter rate ratio[4] (95% CI)				
All-cause encounters	0.58 (0.26−1.30)	REF	0.19 (0.04−0.83)	REF
Neurological encounters	0.79 (0.33−1.92)	REF	0.14 (0.02−0.82)	REF

[1]Mean travel time to UCDCH (minutes): telemedicine cohort=153.4 (SD 46.7), in-person cohort=153.4 (SD 47.2)
[2]Mean travel time to neurology clinic (minutes): telemedicine cohort=20.6 (SD 24.4), in-person cohort=23.5 (SD 23.1)
[3]Inpatient admissions only
[4]Adjusted insurance status, median household income, travel time to UCDCH (for time to neurology clinic-matched sample only), presence of a complex chronic condition and neurology clinic diagnosis category

CONCLUSION

The low numbers and urban clustering of pediatric subspecialists creates barriers to timely and routine access to care for children in non-urban communities. This can adversely impact their clinical outcomes, adherence to medical appointments, and hospital utilization. To address access disparities in its 33-county service area, UC Davis Children's hospital (UCDCH) has been providing consultations using telemedicine in nearly 25 different inpatient and outpatient subspecialties since 1996. In this study, we evaluated the effectiveness of two subspecialty telemedicine programs; the Pediatric Critical Care Telemedicine Program through which UCDCH's pediatric critical care physicians provide consultations to community EDs, and the Pediatric Neurology Telemedicine program through which UCDCH's pediatric neurologists provide consultations at primary care provider's offices in rural and underserved communities.

In Chapter 1, we evaluated the impact of pediatric critical care telemedicine on patients' severity of illness upon presentation to UCDCH's Pediatric Intensive Care Unit (PICU). Higher severity of illness is of concern as it may result in higher morbidity, higher mortality and higher resource utilization. We hypothesized that the telemedicine program would result in better patient care prior to transfer and lower patients' severity of illness upon arrival the PICU. We found that patients transferred from referring, non-pediatric EDs with telemedicine capabilities were significantly less sick upon arrival to the PICU even after adjusting for confounders, suggesting more appropriate stabilization of children transferred from EDs with telemedicine capabilities. Further, among a sub-cohort of children from hospitals that initiated telemedicine during the study period, those transferred during the post-telemedicine period were significantly less sick upon arrival to the PICU than those transferred during the pre-telemedicine period. We also found that standardized mortality ratios (O/E ratios) were lower than 1.0 for children admitted from EDs with telemedicine, and higher than 1.0 for children admitted from EDs without telemedicine. These findings suggest that access to telemedicine consultations with pediatric critical care specialists during the initial treatment of children in non-pediatric EDs might offer an opportunity to reduce mortality.

In Chapter 2, we evaluated whether telemedicine improves access to care for underserved patients by comparing appointment completion between the in-person and telemedicine pediatric neurology clinics. We hypothesized that patients would be equally or more likely to complete appointments scheduled over telemedicine as compared to the appointments scheduled in the in-person clinics. We found that children completed 73% and 65% of their scheduled appointments in the telemedicine clinics and in-person clinics, respectively. Even after adjusting for confounders including demographic and clinical differences between patients, the odds of visit completion were 57% higher in the telemedicine clinics. The adjusted odds of appointment completion remained higher in the telemedicine cohort after matching on travel time to the site of care and travel time to UCDCH.

In Chapter 3, we evaluated the impact of the pediatric neurology telemedicine program on patients' utilization of hospital services. We hypothesized that patients who received pediatric neurology care using telemedicine would have comparable or fewer hospital encounters than similar patients who receive in-person care at UCDCH. We found the rate of all-cause hospital encounters to be nearly four times lower, and the rate of neurological condition-related hospital encounters to be almost twice as low among children who received pediatric neurology consultations over telemedicine in their local communities compared to children who received care by travelling to the in-person clinic at UCDCH. Our finding of lower hospital use among the telemedicine cohort remained significant and consistent even after adjusting for confounders.

To summarize, our results suggest that by improving subspecialist availability and enhancing care coordination between providers, telemedicine may reduce disparities in patients' receipt of necessary care, improve clinical outcomes, enhance appointment adherence and reduce the utilization of hospital services. Our study adds to the limited but growing body of research confirming the effectiveness of subspecialty telemedicine care for children in rural and underserved communities. Future studies should evaluate the effectiveness of telemedicine using a randomized control design to minimize confounding bias in the association measures. Specifically, future studies for Chapter 1 should analyze outcomes associated with telemedicine when consultations are provided at the patient-level. For Chapter 2, future studies should investigate the specific reasons for higher appointment completion in telemedicine clinics compared to in-person clinics among similar, access-matched patients. For Chapter 3, a future study should include encounters of UCDCH neurology clinic patients (telemedicine and in-person) at all hospitals in the region.