Impact of Statewide Telestroke Network on Acute Stroke Treatment in Hawai‘i

Hally M. Chaffin BA; Kazuma Nakagawa MD, FAAN, FAHA; and Matthew A. Koenig MD, FNCS

Abstract

Hawai‘i faces unique challenges in providing access to subspecialty care, particularly on the islands outside of O‘ahu. Telemedicine allows remote treatment of patients with acute ischemic stroke by a neurologist with stroke expertise. The Hawai‘i Telestroke Program was implemented in 2012 to connect hospitals with limited neurology coverage to a tertiary stroke center on O‘ahu with 24/7 stroke neurology coverage. By 2017, seven hospitals were included in the program. The clinical data and revascularization therapy rate for all telestroke cases between January 2012 and July 2017 were analyzed. Annual telestroke consultations increased from 11 in 2012 to 203 in 2016. Among a total of 490 telestroke consultations, 318 patients (64.9%) were diagnosed with ischemic stroke while the remaining 172 patients had other diagnoses. Revascularization therapies, including intravenous tissue plasminogen activator and mechanical thrombectomy, were provided in 190 patients (38.8%). Using the discharge modified Rankin Scale, 141 (44.3%) patients were functionally independent at the time of hospital discharge, while 162 (50.9%) were disabled or dependent, and 15 (4.7%) died while in the hospital. Of the 490 telestroke consultations, 151 patients (30.8%) were transferred to the hub hospital while 69.2% of patients were able to remain in their local hospital. In summary, development of the Hawai‘i Telestroke Program resulted in an increasing number of acute telestroke consultations and revascularization therapies at seven hospitals with limited neurological subspecialty coverage. Utilization of telemedicine in acute stroke treatment is feasible and may help address existing disparities of subspecialty care in Hawai‘i.

Keywords

acute ischemic stroke, telemedicine, tissue plasminogen activator, inter-hospital transfer, functional outcomes, stroke mimics

Abbreviations and Acronyms

AIS = acute ischemic stroke
DTN = door-to-needle
IV tPA = intravenous tissue plasminogen activator
NIHSS = National Institutes of Health Stroke Scale
mRS = modified Rankin Scale
sICH = symptomatic intracranial hemorrhage
TIA = transient ischemic attack

Introduction

The geography of an archipelago presents unique challenges in access to healthcare resources for Hawaii's 1.4 million residents. Limited access to tertiary care and a statewide physician shortage, particularly on the Hawaiian Islands outside of O‘ahu, has resulted in disparities in subspecialty care.[1–3] While physician shortages apply across all specialties, the neurologist shortage has been reported to be especially substantial, ranging between a 38%-100% deficit in the number of neurologists needed on the Hawaiian Islands outside of O‘ahu based on population.[4] The demand for physicians with neurological expertise is expected to increase further with an aging population.

Stroke has been identified as the third-leading cause of death in Hawai‘i.[5] Significant improvement in neurological deficits and functional outcome can be seen when acute ischemic stroke (AIS) is treated with emergency revascularization therapies such as intravenous tissue plasminogen activator (IV tPA) or mechanical thrombectomy. The treatment rate for IV tPA in Hawai‘i has historically varied based on the geographic location of the patient at presentation[1–3] with a statewide treatment rate of 5.5% between 2010-2015.3 In 2012, a Stroke Task Force was convened by the Hawai‘i Department of Health to address disparities in stroke treatment across the state. A 2014 report to the Hawai‘i legislature identified that 14.3% of hospitals had no access to a neurologist and 28.6% of hospitals reported door-to-needle (DTN) times for IV tPA administration to be greater than 60 minutes.[1] It was postulated that limited access to neurologists with stroke expertise was one of the main factors leading to low utilization of revascularization therapies and delay in administration of IV tPA.

One possible solution to address disparities in subspecialty care is the use of telemedicine. Telemedicine or more specifically "telestroke" is an increasingly viable option for hospitals with limited access to neurologists with stroke expertise.[6] The 2018 American Heart Association (AHA) guidelines now recommend the use of telestroke evaluation if in-person stroke expertise is not available.[7] Telestroke programs link "spoke" hospitals without 24-hour stroke expertise with "hub" hospitals, which are usually designated Primary or Comprehensive Stroke Centers with 24/7 neurological coverage. Two-way video-conferencing allows the neurologist at the hub hospital to immediately assess the stroke patient at the spoke hospital and make treatment recommendations such as IV tPA and/or mechanical thrombectomy if warranted. Additionally, telestroke programs allow the neurologist at the hub hospital to triage whether the AIS patient needs to be transferred to the hub hospital for a higher level of care. This allows AIS patients that do not require a higher level of care to remain at the spoke hospital, minimizing the cost of unnecessary inter-hospital transfer. Numerous studies assessing the impact of telestroke programs report improved IV tPA administration rates and DTN time quality metrics, after implementation of telestroke programs.[8–10]

The Hawai‘i Telestroke Program was established in 2012 to provide stroke care through telemedicine for patients at hospitals throughout Hawai‘i where timely access to a stroke neurologist is limited. Based out of the Queen's Medical Center Punchbowl, the program subsequently expanded to seven spoke hospitals on four islands by 2017. We hypothesized that the telestroke program would increase IV tPA treatment rates and reduce treatment delays with a safety profile that is similar to in-person stroke care.

Methods

The project was supported by two grants from the Hawai‘i Department of Health Neurotrauma Special Fund. From its inception in 2012, the Hawai‘i Telestroke Program gradually expanded its spoke hospitals to include seven hospitals on four islands. These hospitals were connected to the hub hospital at The Queen's Medical Center Punchbowl via synchronous audio-video telemedicine equipment. During the study period, we used mobile wireless telemedicine carts manufactured by Interactive Care Technologies which included a remote pan-tilt-zoom camera that was accessible to the on-call neurologist using a web-based portal. For some hospitals, we used Polycom mobile telemedicine carts and Cisco Jabber software for two-way video calls.

All consecutive patients who were activated as acute stroke telemedicine consults from January 2012 to July 2017 were included in a prospectively collected clinical database that was used to report ongoing data to the grant funding agency. This study was based on a planned retrospective analysis of the first 500 patients in the telestroke clinical database with supplemental information collected by retrospective review of the electronic medical record (EMR) for missing data fields. The Queen's Institutional Review Committee approved the retrospective analysis and publication of these data with waiver of individual informed consent.

The Queen's Medical Center Punchbowl is a 505-bed hospital located on O‘ahu, the largest tertiary referral center for the Pacific Basin. It was the only Joint Commission-certified Primary Stroke Center in Hawai‘i until 2015 and it remains the only Hawai‘i hospital with a dedicated neurocritical care unit. During the study period, the telestroke program was covered by two board-certified vascular neurologists and two board-certified neurointensivists who were also vascular neurology trained. The neuro-interventional program was covered by one board-certified neuro-interventionalist. In 2017, the Queen's Medical Center Punchbowl admitted 609 ischemic strokes and performed 37 mechanical thrombectomies.

The spoke hospitals (number of licensed beds, distance to the hub hospital) were: Moloka‘i General Hospital (15 beds, 57 miles by air), Hilo Medical Center (157 beds, 218 miles by air), Wahiawa General Hospital (53 beds, 16 miles by ground), Maui Memorial Medical Center (214 beds, 97 miles by air), North Hawai‘i Community Hospital (42 beds, 178 miles by air), Kona Community Hospital (76 beds, 184 miles by air), and Queen's Medical Center West O‘ahu (80 beds, 12 miles by ground).

Telestroke consults were initiated by providers at spoke hospitals for Emergency Department (ED) patients and hospital inpatients presenting with symptoms suggestive of AIS within 6 hours of the time the patient was last known to be normal. This time window was selected because, at the time of the study, mechanical thrombectomy was recommended for large vessel occlusion strokes within 6 hours of symptom onset.[11] These patients were treated before the recommended time window for mechanical thrombectomy was extended to 16-24 hours.[12]

Patients were subsequently evaluated by a hospital-employed on-call neurologist at the hub hospital using two-way synchronous audio-video telecommunications. Available imaging was also transmitted to and reviewed by the hub neurologist using an encrypted imaging file-sharing software (BEAM, OneMedNet) within the hub hospital picture archiving and communications systems (PACS). The hub neurologist also had access to patient laboratory values and vital signs through the EMR. The neurologist had direct access to the EMR at three of the spoke hospitals which are in the same health care system and indirect access to the EMR at other hospitals through Epic CareEverywhere and Hawai‘i Health Information Exchange (HHIE). For non-Epic hospitals, clinical documentation was transmitted to the spoke hospital using an auto-fax functionality in Epic.

The hub neurologist made recommendations for or against IV tPA and mechanical thrombectomy based on clinical judgment. Providers also made triage recommendations to either transfer the patient to the hub hospital or manage the patient at the spoke hospital based on patient characteristics and local resources. The hub neurologists occasionally utilized telemedicine to access AIS patients at the hub hospital. For the purpose of this study, telemedicine use for the hub hospital was excluded from the final analyses.

The prospective clinical database collected information on patient demographics (age, sex, spoke hospital, self-reported ethnicity/race, etc) and stroke risk factors (hypertension, diabetes, atrial fibrillation, prior stroke, etc) from clinical documentation in the EMR. The initial National Institutes of Health Stroke Scale (NIHSS) score, symptom onset time, and telemedicine response and connection times were recorded by the hub neurologists. The NIHSS is the standard measure of functional disability for acute stroke where no disability is 0 and maximum disability is 42 based on standardized examination with high inter-rater validity.[13] One of the major quality metrics for acute stroke treatment, DTN time for IV tPA, was also recorded in the database and confirmed with review of EMR documentation. The DTN time is defined as the interval from patient arrival to time of initiating IV tPA, and shorter times reflect more ef-

ficient care processes. Outcomes were retrospectively assessed based on review of the EMR upon hospital discharge based on the modified Rankin Scale (mRS) score. The mRS is the most commonly used post-stroke disability scale where 0 is asymptomatic, 1 is symptoms without disability, 2 is slight disability but independent, 3 is moderate disability but able to ambulate, 4 is moderately severe disability, 5 is bedridden, and 6 is dead.[14] The hub hospital only started routinely collecting the 90-day mRS data in 2016 so prospectively collected 90-day mRS data was not consistently available for this study period. Symptomatic intracerebral hemorrhage (sICH) was also recorded in the database as a complication of revascularization therapies and verified based on retrospective review of relevant imaging by the principal investigator (MAK). Determination of sICH was based on the presence of new intracerebral hemorrhage within 24 hours of IV tPA administration and an increase in the NIHSS score by ≥4 points according to standard criteria.[15,16] The final diagnosis of AIS was determined by presence of visible stroke on subsequent MRI or CT imaging or persistent disability attributable to stroke in the opinion of the treating physician. "Stroke mimic" was defined as a final diagnosis other than stroke and no visible stroke on subsequent MRI or CT imaging.

Statistical Analysis

The data were summarized by descriptive statistics using SPSS version 24.0 (SPSS IBM Inc., Chicago, IL). This was a descriptive study of the entire cohort without any attempt to perform pre-specified two-group comparisons.

Results

From its inception in January 2012 to July 2017, the Hawai'i Telestroke Program conducted a total of 500 telemedicine-based consultations for patients with suspected AIS. Among these, 10 telestroke consultations were performed to access suspected AIS patients at the hub hospital and these were excluded from the final analyses. A total of 490 telestroke consultations were conducted to access patients at the spoke hospitals and were included in the final analyses. Clinical characteristics of all included patients are shown in Table 1. Of the total cohort, 318 patients (64.9%) were ultimately diagnosed with stroke while the remaining 172 patients had other diagnoses.

Overall, 190 (38.8%) patients were treated with revascularization therapies via telestroke consultation (Table 2). Of those who were treated, 183 received IV tPA alone, 22 received IV tPA and mechanical thrombectomy, and 7 received mechanical thrombectomy only. The median time from patient arrival to telestroke consult activation was 15.5 minutes and the median telestroke activation to connection establishment (response time) was 6 minutes.

Among the 318 patients who were diagnosed with AIS, the distribution of discharge mRS is shown in Figure 1. Using discharge mRS 0-2 as the standard definition of "functional

Table 1. Clinical Characteristics	
N	490
Age, years, median [IQR]	68 [56, 78]
Sex, female, n (%)	228 (46.5)
Race/Ethnicity, n (%)	
White	157 (32.0)
Asian, non-Filipino	78 (15.9)
Filipino	117 (23.9)
Native Hawaiian or other Pacific Islander	128 (26.1)
Other or unknown	10 (2.0)
Hypertension, n (%)	313 (63.9)
Diabetes mellitus, n (%)	132 (26.9)
Atrial fibrillation, n (%)	105 (21.4)
Hyperlipidemia, n (%)	140 (28.6)
Coronary artery disease	62 (12.7)
Previous TIA or stroke, n (%)	144 (29.4)
Anticoagulant use, n (%)	84 (17.1)
Initial NIHSS, median [IQR], AIS patients only (n=318)	5 [2, 11]
Stroke Subtype, n (%), AIS patients only (n=318)	
Large artery atherosclerosis	86 (17.6)
Cardioembolism	149 (30.4)
Small vessel disease/lacunar stroke	55 (11.2)
Other determined etiology	8 (1.6)
Undetermined etiology	13 (2.7)
Unable to determine	7 (1.4)

AIS = acute ischemic stroke; IQR = interquartile range;
NIHSS = National Institutes of Health Stroke Scale; TIA = transient ischemic attack

Table 2. Process Measures and Performance	
N	490
Any revascularization therapy, n (%)	190 (38.8)
IV tPA	183 (37.3)
IV tPA + Mechanical Thrombectomy	22 (4.5)
Mechanical Thrombectomy only	7 (1.4)
Onset-to-Arrival, min, median [IQR]	70.0 [45.0, 123.5]
Arrival-to-Stroke Code Activation, min, median [IQR]	6.0 [0, 15.0]
Arrival-to-Telestroke Activation, min, median [IQR]	15.5 [7.0, 31.0]
Telestroke Activation-to-Connection Establishment, min, median [IQR]	6.0 [4.0, 10.0]
"Door-to-Needle" Time, min, median [IQR]	47.0 [39.0, 62.0]
Outcome of Telestroke Encounter, n (%)	
Not AIS ("stroke mimics")	172 (35.1)
AIS, no treatment, remain at spoke hospital	115 (23.5)
AIS, treatment, remain at spoke hospital	52 (10.6)
AIS, no treatment, transfer to hub hospital	26 (5.3)
AIS, treatment, transfer to hub hospital	125 (25.5)

AIS = acute ischemic stroke; IQR = interquartile range;
IV tPA = intravenous tissue plasminogen activator

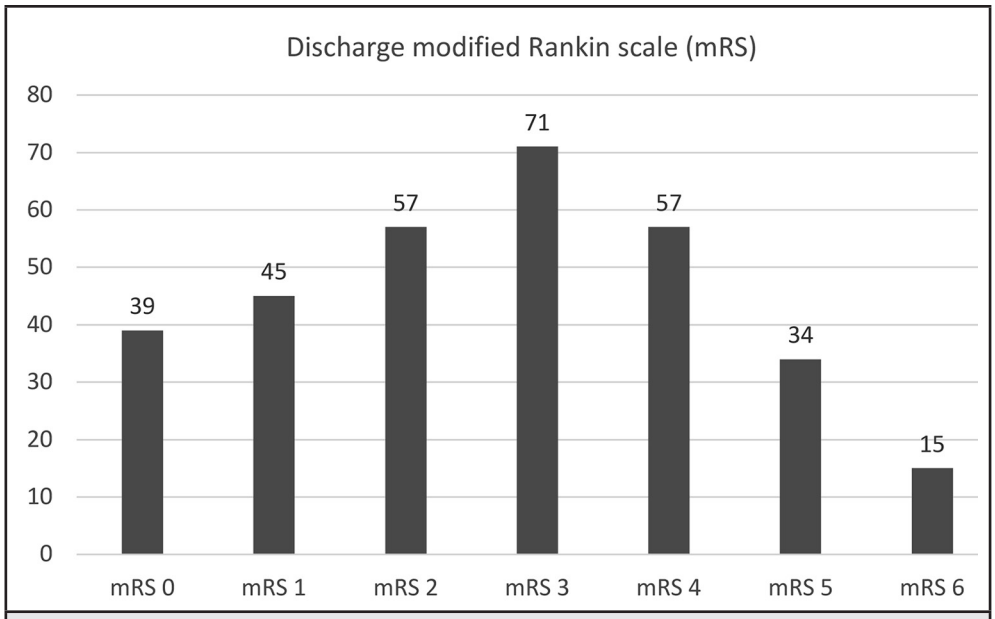

Figure 1. Distribution of mRS at Hospital Discharge for Patients Diagnosed with AIS (n=318) Where 0 is Asymptomatic, 1 is Symptoms Without Disability, 2 is Slight Disability but Independent, 3 is Moderate Disability but Able to Ambulate, 4 is Moderately Severe Disability, 5 is Bedridden, and 6 is Dead

independence", 141 (44.3%) patients in this study were considered independent at the time of hospital discharge, while 162 (50.9%) were disabled or dependent (mRS 3-5), and 15 (4.7%) died while in the hospital (mRS 6). For the subset of 26 patients who were treated with mechanical thrombectomy, median mRS at discharge was 4.0 [3.0, 5.0].

Temporal trends of telestroke consult utilization show a consistent increase from 2012 to 2017 (Table 3). This increase reflects the growth of the Hawai'i Telestroke Program in which the number of telestroke spoke hospitals grew from 1 in 2012 to 7 in 2017 as well as increased per-site utilization. The aggregate median DTN for IV tPA for the spoke hospitals is shown in Table 4. The median DTN across all spoke hospitals was less than 60 minutes during the study period, which is the current national benchmark.[7]

Of the 490 telestroke consultations, 151 patients (30.8%) were transferred to the hub hospital for further tertiary care while 69.2% of patients were able to remain in the spoke hospital for treatment. Among those AIS patients who were treated with IV tPA, 52 patients were able to remain at the spoke hospital while 125 patients were transferred to the hub hospital. Twenty-six patients with AIS who were not treated with IV tPA were also transferred to the hub hospital. Triage decisions were based on local capacity at the spoke hospital and need for higher level of care as well as patient and provider preferences. Two of the spoke hospitals do not have MRI, carotid imaging, and/or echocardiography available on-site. At these hospitals, even routine stroke patients who were not treated with IV tPA required transfer to the hub hospital. In other cases, high risk patients with large strokes who would benefit from monitoring in the neurocritical care unit or may have needed decompressive craniectomy were transferred to the hub hospital.

Table 3. Temporal Trends of Telestroke Consultation

Temporal Trends in Number of Telestroke Consults by Year	
Year	**N**
2012	11
2013	18
2014	29
2015	130
2016	203
2017*	99

*last data in July 2017

Table 4. Temporal Trends in Door-to-Needle Time by Year

Year	Minutes, median [interquartile range]
2012 (n = 4)	72.5 [56.8, 95.0]
2013 (n = 11)	60.0 [35.0, 62.0]
2014 (n = 11)	45.0 [42.0, 62.0]
2015 (n = 48)	44.0 [38.0, 58.8]
2016 (n = 69)	50.0 [40.5, 63.5]
2017* (n = 40)	43.5 [35.0, 60.0]

*last data in July 2017

Among patients who were treated with revascularization therapies, 11/183 (6.0%) had sICH. Five of these patients were treated with mechanical thrombectomy in addition to IV tPA while 6 patients were treated with IV tPA alone. All of the patients with sICH had poor neurological outcomes at the time of hospital discharge with mRS 3 in 1 patient, mRS 4 in 2 patients, mRS 5 in 4 patients, and in-hospital death in 4 patients.

Despite the criterion for telestroke activation by the spoke hospital being an initial clinical impression of AIS, 172 patients (35.1%) were ultimately diagnosed with stroke mimics by the hub neurologist. These patients had final diagnoses of conversion disorder (n=57), transient ischemic attack (TIA) (n=33), encephalopathy (n=23), spontaneous ICH (n=20), seizure (n=19), migraine (n=9), and other causes (n=11). Of the 183 patients who were treated with IV tPA, 9 patients (4.9%) were ultimately diagnosed with a stroke mimic. Six patients were diagnosed with conversion disorder, 2 patients with seizure, and 1 patient with migraine. Of the 9 stroke mimic patients who were treated with IV tPA, none had sICH and all were eventually discharged to home.

Discussion

National and regional physician shortages have encouraged the development of programs that allow patients in rural or otherwise underserved areas to receive similar care to those treated at tertiary academic medical centers. One of the most visible developments has been the implementation of telemedicine, which has been shown to be safe and effective for evaluation and treatment of AIS.[16-18]

Other regions have successfully implemented telestroke programs which have connected smaller, rural hospitals with Primary and Comprehensive Stroke Centers. A pilot program implemented in southeastern Louisiana that emphasized first responder training in addition to early telemedicine activation showed reduction in time to neurology consult and IV tPA administration rates that were higher than the national average.[19] Implementation within the Kaiser Permanente system in Southern California increased IV tPA administration for AIS by 4.6% and brought IV tPA administration rates at spoke hospitals in line with those at the Comprehensive Stroke Center.[18]

Our study demonstrated a significant increase in telestroke adoption and number of patients treated with revascularization therapies during the study period. Of the 490 telestroke consultations, 309 patients (69.2%) were able to remain in their local community hospital for treatment. Triage decisions regarding which patients required inter-hospital transfer were based on recommendations from the hub neurologist and spoke physician as well as patient preferences. These decisions were largely based on local resources available at the spoke hospital, local experience with post-IV tPA monitoring, and patient characteristics such as anticipated stroke size, need for neurocritical care monitoring, or need for mechanical thrombectomy. Because of the island geography, the cost of inter-hospital transport between islands has been reported to be at least $15,000 per patient and as high as $70,000 in some locations.[20,21] Considering these costs, we anticipate that appropriate triage of stroke patients based on telemedicine will result in significant healthcare cost savings.

In this study, 339 telestroke cases did not require transfer to the hub hospital, 172 of whom were located on one of the neighbor islands outside of Oʻahu. It is difficult to estimate the exact number of patients who may have been transferred to the hub hospital without the telestroke program. However, if the maximal potential cost savings were to be estimated with an assumption that all 172 cases would have been transferred using air ambulance services, it would be approximately $6.2 million over the study period based on an average estimated air ambulance cost of $36,000 per inter-island medical transfer.[21] If we were to make a conservative estimate of 10% preventable transfer among these neighbor island cases, it would still be $620,000 in cost savings over the study period.

Since the implementation of the Hawaiʻi Telestroke Program, according to the Get With the Guidelines – Stroke database, the rate of DTN times under 60 minutes in Hawaiʻi has improved from 43.6% of patients in 2012 to 77.3% in 2017. Revascularization therapies for AIS patients at all Hawaiʻi hospitals also improved from 6% to 15.3% between 2012 and 2017. While these improvements may not be directly attributable to the Hawaiʻi Telestroke Program alone, these findings indicate an overall improvement in the number of patients in Hawaiʻi who received appropriate, timely therapy for AIS during the study period.

One of the strengths of telestroke care is that it has been found to be as safe as treatment based on in-person assessment in other studies.[16,22] The rate of inadvertent IV tPA administration in patients with stroke mimics and the rate of sICH in AIS patients treated with IV tPA are two safety concerns frequently discussed in reference to telestroke programs. Stroke mimics are those patients who initially present with symptoms similar to AIS but are ultimately determined to have a different diagnosis, such as seizures, conversion disorder, or TIA. Stroke mimics are estimated to make up around 15% of those presenting with AIS symptoms and present a dilemma for providers caring for these patients.[23,24] Ideally, stroke mimics are accurately identified prior to administration of IV tPA. However, time constraints for IV tPA administration often make the advanced imaging or other tests that could differentiate between AIS and stroke mimics difficult to employ. Prior case series have reported a low incidence of complications such as sICH when patients with stroke mimics are inadvertently treated with IV tPA.[23-26]

Remote neurological examination based on telemedicine requires different clinical skills compared to in-person neurological

examination which may raise the potential for a higher rate of inadvertent IV tPA treatment in stroke mimics. In the present study, 35.1% of patients who received a telestroke consult were ultimately determined to be stroke mimics. Of the patients treated with IV tPA in the present study, 11 patients (4.9%) were subsequently diagnosed with a stroke mimic. Our findings were similar to a prior large multi-center study that reported 32.6% of telestroke activations were ultimately diagnosed with a stroke mimic.[27]increasing numbers of SM patients are likely being evaluated via Telestroke. We developed a model to prospectively identify ischemic SMs during Telestroke evaluation. METHODS AND RESULTS: We analyzed 829 consecutive patients from January 2004 to April 2013 in our internal New England-based Partners TeleStroke Network for a derivation cohort, and 332 cases for internal validation. External validation was performed on 226 cases from January 2008 to August 2012 in the Partners National TeleStroke Network. A predictive score was developed using stepwise logistic regression, and its performance was assessed using receiver-operating characteristic (ROC Two prior studies reported stroke mimic rates of 7% and 7.8% among patients treated with IV tPA based on telestroke consultation which was similar to the stroke mimic rate among patients treated with IV tPA based on in-person examinations in their respective cohorts.[28,29]

Some studies have attempted to identify factors that are associated with higher likelihood that a patient's symptoms are caused by a stroke mimic.[27] These studies suggest that stroke mimics are more common in patients who are younger, present with a minor neurological deficit, and have lower NIHSS scores.[23,24,27] Evaluation and IV tPA treatment oversight by a neurologist reduces the likelihood that a stroke mimic patient will be administered IV tPA compared with emergency physicians acting without neurological consultation.[30] Telestroke programs that connect patients with neurologists are likely to improve appropriate IV tPA administration rates and reduce inadvertent treatment of stroke mimics.

An uncommon but significant complication after IV tPA administration is sICH. Rates of sICH in AIS patients treated with IV tPA have been shown to be no different in telestroke assessments when compared with in-person assessments.[19] In the present study, 6% of patients who were treated with revascularization therapies developed sICH over the course of the study period. A disproportionate number of patients with sICH were treated with the combination of IV tPA and mechanical thrombectomy rather than IV tPA alone. The sICH rate was similar to the rate reported in the original National Institute of Neurological Disorders and Stroke (NINDS) treatment trial and the package labeling for IV tPA (6.4%)[31] but higher than post-marketing surveillance data from the Safe Implementation of Treatment in Stroke (SITS) registries (1.6-2.2%).[15,32] A meta-analysis of prior observational studies of telestroke programs reported a range of sICH of 1-8% which was similar to control groups of patients treated with IV tPA in-person.[8]

This study has some important limitations based on the geography and healthcare systems in Hawai'i and the retrospective nature of the study design. First, due to the unique island geography of Hawai'i, the results may not be generalizable to healthcare systems in other regions. Second, longer term functional outcomes were not available for many of the patients in this study, particularly those who were not transferred to the hub hospital. Because of this limitation, the long-term safety and outcomes of telestroke treatment are not known. Third, although the study was based on a prospectively collected database, some retrospective chart review was required to obtain data regarding the final diagnosis, imaging results, and functional outcomes. Retrospective EMR review was often required for patients who were not transferred to the hub hospital. Investigators conducting these retrospective reviews were not blinded to the initial treatment decisions which could introduce outcome ascertainment bias.

The unique environment of the Hawaiian Islands presents many challenges to care for patients on islands other than O'ahu who may not have timely access to a neurologist. While stroke is a leading cause of death and disability in Hawai'i, patients living on other islands and in rural areas have historically had difficulty accessing the same quality stroke care as those patients living in urban Honolulu. The Hawai'i Telestroke Program has sought to bridge the gap for these patients through the implementation of a telemedicine program that connects hospitals with acute stroke care. The program has been shown to be safe and effective at improving rates of revascularization therapies and reducing DTN time across all hospitals where the program was implemented. In future studies it would be beneficial to assess long-term outcomes of patients treated with IV tPA and outcome trends at individual hospitals within the Hawai'i Telestroke Program.

Conflict of Interest

None of the authors identify any conflicts of interest.

Acknowledgements

This project was supported by two grants from the Hawai'i Department of Health Neurotrauma Special Fund.

Authors' Affiliations:
- The Queen's Medical Center, Neuroscience Institute, Honolulu, HI (HMC, KN, MAK)
- Department of Medicine, John A. Burns School of Medicine, University of Hawai'i, Honolulu, HI (KN, MAK)

Correspondence to:
Matthew A. Koenig MD, FNCS;The Queen's Medical Center, 1301 Punchbowl St., Neuroscience Institute–QET 5, Honolulu, HI 96813; Email: mkoenig@queens.org

References

1. Rosen L. Stroke Task Force- final report to the 28th Legislature. http://health.hawaii.gov/opppd/files/2015/06/Stroke-Task-Force.pdf. Accessed March 7, 2019.
2. Fuddy LJ. Chronic disease disparities report 2011: social determinants. http://health.hawaii.gov/chronic-disease/files/2013/12/CD_BurdenReport_FINAL.pdf. Accessed March 7, 2019.
3. Ideta TR, Lim E, Nakagawa K, Koenig MA. Racial and ethnic disparities in hospital mortality among ischemic stroke patients in Hawaii. *J Stroke Cerebrovasc Dis*. 2018;27(6):1458-1465.
4. Withy K, Mapelli P, Perez J, Finberg A, Green J. Hawai'i physician workforce assessment 2016: improvement in physician numbers but physician suicides of concern. *Hawaii J Med Public Health*. 2017;76(3 Suppl 1):3-9.
5. Hawaii Health Data Warehouse. Deaths in Hawaii due to stroke. http://hhdw.org/wp-content/uploads/AAMR_Stroke_3AGG.pdf. Accessed March 7,2019.
6. Schwamm LH, Holloway RG, Amarenco P, et al. A review of the evidence for the use of telemedicine within stroke systems of care: A scientific statement from the American Heart Association/American Stroke Association. *Stroke*. 2009;40(7):2616-2634.
7. Nguyen-Huynh MN, Klingman JG, Avins AL, et al. Novel telestroke program improves thrombolysis for acute stroke across 21 hospitals of an integrated healthcare system. *Stroke*. 2018;49(1):133-139.
8. Sanders KA, Patel R, Kiely JM, Gwynn MW, Johnston LH. Improving telestroke treatment times in an expanding network of hospitals. *J Stroke Cerebrovasc Dis*. 2016;25(2):288-291.
9. Ranta A, Lanford J, Busch S, et al. Impact and implementation of a sustainable regional telestroke network. *Intern Med J*. 2017;47(11):1270-1275.
10. Powers WJ, Rabinstein AA, Ackerson T, et al. 2018 Guidelines for the early management of patients with acute ischemic stroke: a guideline for healthcare professionals from the American Heart Association/American Stroke Association. *Stroke*. 2018;49:e46-e99.
11. Berkhemer OA, Fransen PSS, Beumer D, et al. A randomized trial of intraarterial treatment for acute ischemic stroke. *N Eng J Med*. 2015;372(1):11-20.
12. Nogueira RG, Jadhav AP, Haussen DC, et al. Thrombectomy 6 to 24 hours after stroke with a mismatch between deficit and infarct. *N Eng J Med*. 2018;378(1):11-21.
13. Goldstein LB, Bertels C, Davis JN. Interrater reliability of the NIH stroke scale. *Arch Neurol*. 1989;46(6):660-662.
14. van Swieten JC, Koudstaal PJ, Visser MC, Schouten HJ, van Gijn J. Interobserver Agreement for the Assessment of Handicap in Stroke Patients. *Stroke*. 1988;19(5):604-607.
15. Wahlgren N, Ahmed N, Dávalos A, et al. Thrombolysis with alteplase for acute ischaemic stroke in the Safe Implementation of Thrombolysis in Stroke- Monitoring Study (SITS-MOST): an observational study. *Lancet*. 2007;369(9558):275-282.
16. Kepplinger J, Barlinn K, Deckert S, Scheibe M, Bodechtel U, Schmitt J. Safety and efficacy of thrombolysis in telestroke: A systematic review and meta-analysis. *Neurology*. 2016;87(13):1344-1351.
17. Meyer BC, Raman R, Hemmen T, et al. Efficacy of site-independent telemedicine in the STRokE DOC trial: a randomised, blinded, prospective study. *Lancet Neurol*. 2008;7(9):787-795.
18. Sauser-Zachrison K, Shen E, Sangha N, et al. Safe and effective implementation of telestroke in a US community hospital setting. *Perm J*. 2016;20(4):11-15.
19. Joshi P, Marino M, Bhoi A, Gaines K, Allen E, Mora J. Implementing telestroke to reduce the burden of stroke in Louisiana. *J Cardiovasc Dis Res*. 2013;4(1):71-73.
20. Nakagawa K, Galati A, Juarez DT. The excess cost of interisland transfer of intracerebral hemorrhage patients. *Am J Emerg Med*. 2015;33(4):512-515.
21. Consillio K. Charges for medevac flights soar in Hawaii. EMS World 2015, https://www.emsworld.com/news/12111684/charges-for-medevac-flights-soar-in-hawaii. Accessed May 1, 2019.
22. Pervez MA, Silva G, Masrur S, et al. Remote supervision of IV-tPA for acute ischemic stroke by telemedicine or telephone before transfer to a regional stroke center is feasible and safe. *Stroke*. 2010;41(1):18-24.
23. Chen Y, Bogosavljevic V, Leys D, Jovanovic D, Beslac-Bumbasirevic L, Lucas C. Intravenous thrombolytic therapy in patients with stroke mimics: baseline characteristics and safety profile. *Eur J Neurol*. 2011;18(10):1246-1250.
24. Chernyshev OY, Martin-Schild S, Albright KC, et al. Safety of tPA in stroke mimics and neuroimaging-negative cerebral ischemia. *Neurology*. 2010;74(17):1340-1345.
25. Winkler DT, Fluri F, Fuhr P, et al. Thrombolysis in stroke mimics frequency, clinical characteristics, and outcome. *Stroke*. 2009;40(4):1522-1525.
26. Förster A, Griebe M, Wolf ME, Szabo K, Hennerici MG, Kern R. How to identify stroke mimics in patients eligible for intravenous thrombolysis? *J Neurol*. 2012;259(7):1347-1353.
27. Ali SF, Hubert GJ, Switzer JA, et al. Validating the telestroke mimic score a prediction rule for identifying stroke mimics evaluated over telestroke networks. *Stroke*. 2018;49(3):688-692.
28. Asaithambi G, Castle AL, Sperl MA, et al. Thrombolytic treatment to stroke mimic patients via telestroke. *Clin Neurol Neurosurg*. 2017;153:5-7.
29. Yaghi S, Rayaz, S, Bianchi N, Hall-Barrow JC, Hinduja A. Thrombolysis to stroke mimics in telestroke. *J Telemed Telecare*. Epub 2012 Oct 3.
30. Scott PA, Silbergleit R. Misdiagnosis of stroke in tissue plasminogen activator-treated patients: characteristics and outcomes. *Ann Emerg Med*. 2003;42(5):1-8.
31. National Institutes of Neurological Disorders and Stroke rt-PA Stroke Study Group. Tissue plasminogen activator for acute ischemic stroke. *N Eng J Med*. 1995;333(24):1581-1587.
32. Wahlgren N, Ahmed N, Dávalos A, et al. Thrombolysis with alteplase 3-4.5 h after acute ischaemic stroke (SITS-ISTR): an observational study. *Lancet*. 2008;372(9646):1303-1309.