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Time is Brain: How a Descriptive Analysis of Telestroke Metrics Can Improve Program Performance

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A doctoral project submitted to the faculty of the Medical University of South Carolina
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In the event of an acute ischemic stroke, 1.9 million neurons are lost in the brain per minute. Since the inception of thrombolytic therapy and mechanical thrombectomy as effective tools in the treatment of acute ischemic stroke, the focal point of quality improvement in this field has become the time to treatment delivery. As rural and more interspersed environments exhibit high disability and mortality rates associated with these acute neurological conditions, inequities in timely care delivered to these patient populations persist. Limitations in access are now abated by the extension of neurologist expertise into these areas via Telestroke. This study seeks to understand variation among key performance measurements within a Telestroke network serving New York's Hudson Valley and to determine if more time within this program results in improved performance. A descriptive analysis of several unique time metrics reveals associations among discovered variables that will guide targeted process improvement initiatives and promote evidence-based decision making. It is undetermined whether time within this network results in improved performance, yet the mission of continuously improving the ability to preserve brain tissue in acute stroke patients by reducing the time to treatment is accomplished through constant program monitoring and process improvement.

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CHAPTER I INTRODUCTION

1.1 Background and Need

The Northern Hudson Valley in the state of New York is described by the National Parks Service as a region "dominated by rolling hills, the Catskills, farms, and orchards as well as beautiful river and mountain views." The bucolic attraction of this region quickly becomes a barrier, however, when racing to transfer a patient suffering from an acute ischemic stroke to the nearest hospital with a qualified neurointerventional care team ready to intervene.

EMS Dispatch: "Medvac ETA delayed due to inclement weather conditions – will advise."

Clinical Admin: "Last known well – 11 hours ago, alternate ground option available?"

EMS Dispatch: "Ground ambulance ETA estimated 2-hour delay, holding flight path."

This example of EMS radio chatter is not uncommon in similarly rural segments of the nation with underserved populations. The etymology of the maxim "Time is Brain" stems from efforts to quantify neuronal loss during a large vessel occlusion (LVO), with current estimates at around two million neurons per minute (Desai, 2019). This rate of unrelenting damage reveals a stark directive for stroke programs to minimize the time from last-known-well (LKW) to evaluation and endovascular intervention (Saver, 2006). In these medically underserved environments, acute neurological conditions are associated with high disability and mortality rates relative to their urban and suburban counterparts (Patel, 2019). Limited access stemming from prohibitive distances, clinician shortages, or other socioeconomic constraints contributes to this population's burden of otherwise manageable conditions. When it comes to the unexpected occurrence of a stroke, these variables related to timely access quickly compound into significant implications for timetables of rehabilitation and a patient's quality of life post neurologic event.

A population health approach to this community need guided the New York State Department of Health as it enacted a three-tiered stroke system of care in March of 2019 under NYCRR 405.34, with an objective to more expeditiously and effectively diagnose and triage stroke patients to appropriate facilities (NYSDOH, 2022). New York State now designates hospitals as:

1. Primary Stroke Centers (15 in the region): Capable of treating acute ischemic stroke with IV t-PA (tissue plasminogen activator) and comprehensive supportive care.
2. Thrombectomy Capable Stroke Centers (1 pending certification): Capable of treating large vessel occlusions with intracranial endovascular intervention.
3. Comprehensive Stroke Centers (2 in the region): Capable of treating subarachnoid intracerebral hemorrhage with neurosurgical services.

A cohesive stroke care system such as this provides the governance, infrastructure, and standardized decision-making algorithms necessary to meet performance metrics related to time targets and performance measures. Some critical examples of these measures include "door to stroke team assessment" (goal: ≤ 15 minutes) and "time to intravenous thrombolytic therapy" (goal: ≤ 60 minutes) (NYSDOH, 2022). Telestroke networks, a specialized segment of teleneurology services, have been identified as an established means of augmenting the timely delivery of acute stroke care in rural areas by extending the reach of neurologists and their diagnostic expertise (Sami, 2021). To observe a telestroke visit is to witness the gestalt of clinical protocols coming together to evaluate the disposition of a patient. From the activation of an on-call neurologist, to the booting up of a telestroke cart armed with a camera miles away, to the interpreting of CTA imaging, to the ultimate decision of prognosis and transfer status based on NIHSS score (The National Institutes of Health Stroke Scale), telestroke is an essential process within the pathway of stroke care.

A multi hospital health system in the Hudson Valley of New York implemented such a telestroke network in 2019 based out of their main campus in Westchester, NY. Through several transfer agreements and coordination with the Department of Health, this health system plays a major role in the delivery of stroke care throughout the region. The effects of the implementation of this particular telestroke program on key quality measures should be evaluated to further understand how health systems with shared missions in this setting may better serve their patient populations.

1.2 Problem Statement

There is a projected 20.5% increase in the prevalence of stroke among United States adults from 2012 to 2030 (Tsao, 2022). In the United States, acute ischemic stroke is the leading cause of disability with over 750,000 cases a year resulting in $30 million of health expenses or lost wages (Patel, 2019). The continuum of care related to the incidence of a stroke, from transfers to surgical intervention to rehabilitation, requires a multidisciplinary approach that is hardly affordable in the modern healthcare landscape. Telestroke acts as a disruptive tool in this journey of care to combat fragmented and costly delivery systems and attempts to create a streamlined medium for patient centered care. In the context of these variables, extending the range of neurologists' expertise through the use of telestroke networks has been demonstrated as an effective means of advancing quality care outwards into underserved communities.

Yet further evaluation of the measured impact of telestroke programs on stroke transfers in the Hudson Valley is necessary to confirm and detail the ability of such interventions to reduce time to care at every possible point in the process. As studies such as those by Scott (2022) reveal, interoperability or other technological barriers (such as low bandwidth in community hospitals) may actually delay the application of crucial thrombolytic therapies such as t-PA (tissue plasminogen activator). These unintended delays and barriers highlight streamlined decision-making infrastructure as a salient prerequisite in the mission of delivering equitable and expeditious care in this field. Meeting this need to effectively address increasing rates of complex neurological conditions requires an intimate awareness of these processes' strengths and limitations. Such research aims to generate evidence to inform health system leaders in response to calls to action to evaluate their own telestroke programs and to seek constant upgrades to their armamentariums.

1.3 Research Questions and Primary Aims

This study seeks to quantify the impact of this health system telestroke network on key quality measures related to timely stroke cases in the Hudson Valley. We ask whether the telestroke network prompted a reduction in the "door to time of Telestroke notification" metric among stroke cases facilitated by this network over time. In following the natural progression of this clinical protocol, determining whether the ensuing "Telestroke notification time to consult time" metric demonstrates any change over time will add to this understanding. These two metrics are associated with an industry standardized goal of 10 minutes or less when target door to needle times are 45 minutes (AHA, 2018). These research questions aim to describe the effectiveness of certain isolated workflows during the acute care window in order to spotlight spoke hospitals and specific areas for targeted quality interventions as we continue to reduce overall time to evaluation and treatment.

1.3.1 Secondary Aims

Descriptive analysis of overall t-PA treatment rates generated by the telestroke program at participating network hospitals within this system will also reveal valuable programmatic trends across locations over time. We posit that the inception of the telestroke network of interest increased t-PA rates across the spoke hospitals as compared to average rates found in the literature. This is another standardized quality benchmark that allows programs to evaluate their impact on population health management at a high level while the more specific timing of triage as noted in our primary aims is a measurement that allows teams to engage in granular performance improvement initiatives.

Finally, an analysis of the overall growth in telestroke consult volume will supplement our understanding of this program's ability to treat a previously unmet community need caused by this acute condition. This study aims to seek valuable information for health systems that are investing in infrastructure to effectively extend the reach of their world-class specialists into medically underserved areas.

2 CHAPTER II SCOPING LITERATURE REVIEW

2.1 Definitions & Implications of Teleneurology

The persistent evolution of the structures and definitions of quality attributed to teleneurology programs demonstrates the need for continued attention to programmatic evaluation. As we seek to promote targeted accessibility of this specialized neurological care, we must also tap the current base of knowledge to quantify current lapses in coverage in underserved geographical environments. Complementary to the goal of continuously improving our ability to preserve brain tissue by reducing the time to treatment is a historical snapshot of standardized guidelines in this field. Get With The Guidelines (GWTG) is a qualified CMS stroke core measures tool created by the American Heart Association (AHA) that serves as a reputable source for this analysis. An immersive review of the current application of technological advancements within the parameters of these modern guidelines further explains how far health systems have come, and how far we have yet to go, in improving the quality of stroke care. A closing summary of operational trends describes the current evidence-based consensus of the effectiveness of these teleneurology models and how innovative time-reducing applications of such models might benefit from this primer.

Comprehensive stroke centers are designated as such because they employ in-house qualified neurologists and have the resources necessary to deliver the highest level of care. Teleneurology is deployed in primary stroke centers, often located in less populated regions, that lack the clinicians and surgical facilities necessary to perform advanced lifesaving interventions. This is a structure well recognized by The American Academy of Neurology (AAN) as an effective means of delivering care to areas with insufficient neurologists. Through the digital interface that connects them, neurologists based out of a comprehensive stroke center will synchronously evaluate a patient, consult with emergency physicians at the local hospital, review uploaded diagnostic imaging, and indicate a transfer status as quickly and safely as possible. Since the inception of this model of care, program leaders and researchers alike seek to reveal the relationship among variables that influence outcomes and costs related to the implementation of these programs.

With the development of new endovascular treatment methods such as mechanical thrombectomy and thrombolytic therapy medications, there has been a predicted rise in acute transfer volume to capable stroke centers (Zerna, 2016). Sonig (2016) applied a retrospective analysis of the National Inpatient Sample (NIS) database to find a mean charge amount of $70,325 for direct stroke hospitalizations compared to a mean charge amount of $97,546 for stroke patients transferred to another facility, with risk-adjusted mortality ratios considered in the regression analysis model. These results describing increased volume and the relative cost of active stroke interventions demonstrate that a telestroke network enabled to efficiently and efficaciously indicate transfers only when necessary is one that saves significant cost for both patients and hospitals. This now well-established clinical pathway and pattern of costly transfers means that continuous empirical data is required to make informed decisions on how to ensure outcomes are being optimized and costs minimized. Efforts to quantify the consequences of delayed care are especially salient to rural regions such as the Hudson Valley that grapple with barriers to access.

2.2 Inequity & Reach

In rural segments of the nation with underserved populations, neurological conditions are associated with high disability and mortality rates (Patel, 2019). Cardinale (2018) provides further detail to describe mortality rates up to 20-40% higher in these rural areas, possibly attributed to lack of access to specialists and other socioeconomic barriers. As Zhang (2018) notes, only 55% of Americans are within a sixty-minute drive from a primary stroke center. In addition to larger distances between patients and the nearest hospital, there is a growing disparity between the number of available qualified neurologists and the need for care within these communities (Wechsler, 2015). Almallouhi (2020) also highlights a dearth of neurological expertise in rural areas in a retrospective review of the Medical University of South Carolina's (MUSC) robust teleneurology service. Their telestroke network, initiated in 2008, demonstrates a successful deployment in rural settings as the program eventually partnered with the health system's teleneurology network to extend its reach to fourteen partner hospitals. As we seek to maintain patients in their own local environments to minimize costs and improve outcomes, teleneurology is a powerful tool in achieving this aim of discharging to home and transferring only when necessary (Sami, 2021).

Hub and spoke models adopt teleneurology to specifically address the increasing prevalence and burden of stroke in areas that are not within immediate reach of qualified specialists. Extending the range of neurologists' expertise through telestroke has been recommended based on several levels of evidence as an effective means of increasing accessibility of quality care into these more vulnerable communities (Schwamm, 2009). The critical time saving objective of these methods is revealed when analyzing existing program's effectiveness and impact on key quality measures over time. As t-PA is demonstrated as an effective treatment only when administered within 4.5 hours of symptom onset, for example, the consequence of delayed access is an increased likelihood of long-term disability (Harvey, 2019). As Sonig (2016) posits in a retrospective analysis, the development of regional stroke transfer algorithms that direct care to the appropriately tiered facility is likely to significantly improve outcomes and reduce costs. No such analyses of the Hudson Valley region's stroke networks have been performed and published.

Brief consideration should also be given to recent policy implications precipitated by the COVID-19 pandemic. The rapid adoption and innovation of telemedicine by the nation's health systems, catalyzed by the sudden shutdown of in-person clinical operations, have further encouraged the implementation of these already popular telestroke networks. With emergency suspensions of inter-state licensure regulations and an increase in reimbursement for virtual visits slowly being reverted, there is now active debate about which Medicare programs should receive permanent coverage status (Wilcock, 2022). Telestroke is recognized as a vanguard in improving outcomes, as its ability to reduce mortality was cited five times in the Congressional Subcommittee on Health's hearing on "The Future of Telehealth" in March of 2021 (www.congress.gov, 2021). The policy precedent for telestroke had already been established as evidenced by the Furthering Access to Stroke Telemedicine (FAST) Act passed by the 115th Congress in 2018. Prior to this Act, Medicare was already reimbursing rural emergency departments for telestroke and telepsychiatry services. FAST ensured that urban emergency departments could also receive the same payments. This legislative recognition, at both the federal and state level, of telestroke's specific importance in addressing population health trends is encouraging for policy makers at our level. It is also an indication that efforts to improve cost efficiency and efficacy in telestroke may fit neatly into value-based care initiatives and should be further studied in this context.

2.3 Quality Standards & Guidelines

On average, someone expires from a stroke every three and a half minutes (Tsao, 2022). The rapid adoption of new care delivery models, including hub and spoke teleneurology networks, means that healthcare leaders must match the growing prevalence of stroke and the pace of innovation with advanced quality benchmarks. A standardized measuring stick in the form of the Centers for Medicare and Medicaid Service's (CMS) stroke mortality quality benchmarks are complemented by the American Heart Association's "Get With The Guidelines – Stroke" (GWTG) registry. This tool utilizes over 5 million patient records to produce a database with bleeding edge performance targets. This allows stroke centers to apply comparable metrics to the development of real time evidence-based programmatic improvements. The GWTG measures are categorized by achievement, quality, descriptive, and reporting measures. "Door to Stroke Team in ≤ 10 minutes" is one such benchmark that we will compare to our own results in this study (AHA, 2018). Such a collection of scientific and standardized measures establishes the foundation upon which programs can translate their own clinical results into best practice (Cardinale, 2018).The New York State Stroke Designation Program and Title 10 NYCRR 405.34: Stroke Services aims to provide guidance for hospitals in the state that are seeking to implement a highly coordinated system of care (NYSDOH, 2019). These designated stroke centers, certified routinely by approved accreditation organizations, must adhere to certain leadership structure, provider availability, EMS communication, transfer agreement, diagnostic service, and patient education requirements defined by the NY department of health. Constructing an evidence-based program using standardized guidelines across a region allows for the safe growth of an accountable statewide service.

The approach of relying on coercive regulatory policy in the form of standardized metrics, such as those constructed by CMS, GWTG, and New York State, is seldomly criticized by stakeholders such as hospitals, insurers, and consumers (Ash, 2012). More specifically, the use of Hierarchical Generalized Linear Models (HGLMs) and other statistical approaches in hospital quality public reporting are sometimes noted as insufficient in accounting for certain variations like case mix. The Committee of Presidents of Statistical Societies (COPSS), charged by the CMS to detail these concerns, recommend that provider performance variation and the masking of low volume performance be addressed by evaluating an expansion of the statistical model to include shrinkage targets (Ash, 2012). COPSS also recommends improved communication of these objectives and methods for public consumption to improve an overall understanding of hospital certifications (Ash, 2012). Any implementation plan of telestroke programs in this regulatory and policymaking framework should consider these potential limitations and leaders should make informed decisions in any efforts to advocate for their rural health networks. Gilchrist (2020) performs a review of policy interventions as a form of monitoring regulatory efficacy in telestroke networks across the nation. This research team found that policy has resulted in the widespread implementation of evidence-supported interventions, but more persistent research is needed to detail the impact of interactions between pre-hospital and in-hospital regulations (Gilchrist, 2020).

2.4 Metrics of Interest

As the consequences of delays embedded within the telestroke process are quantified by standardized outcomes, they should be simultaneously translated into targeted structural improvements (Weschler, 2015). Frameworks for the evaluation of telestroke units typically focus on retrospective data that is most often assessed in the lens of focused patient populations of either one medical center, a telestroke network, or a state or national registry. Researchers such as Gutovitz (2022) and Harvey (2019) apply retrospective statistical analyses of how teleneurology impacted patient populations to study certain common metrics as such as “door to needle time” (referring to the administration of intravenous tissue plasminogen activator (t-PA) upon admission) and “rate of transfer.” Their results not only demonstrate the potential for teleneurology in improving outcomes, but also identify some concerning limitations that should be further studied in diverse environments to encourage optimal operationalization of this technology. Evaluations of research that closely match our metrics of interest (door to Telestroke notification time, Telestroke notification to video consult start time, t-PA rates, and consult volume) will guide the refinement of this study’s methods and reveal useful benchmarks.

2.4.1 Door to Telestroke Notification

When a patient with suspected acute stroke passes through an emergency department’s doors, the clock starts ticking as the code stroke protocol is activated. This moment signifies the start of a clinical evaluation by the emergency physician to determine if a telestroke consult is required. Once indicated, the receiving hospital will use the telestroke network communication infrastructure to notify the Telestroke program that a consult is waiting at their location. Measuring this period of time allows programs to diagnose a very specific grouping of processes. Most studies, however, are designed to measure more common “door to t-PA” or “door to needle” times which indicate the time to t-PA intravenous administration or mechanical thrombectomy. Choi (2019) is an example of a study that utilized a retrospective analysis and regression models to evaluate “door-in door-out (DIDO)” time for mechanical thrombectomy transfers. This study provides a detailed mapping of a stroke service organization, protocols, and implemented interventions over time. The authors found a median DIDO of 86 minutes with a progressive reduction trend from 2015 to 2018 that is attributed to a planned collaborative project to streamline this process (Choi, 2019). Focused monitoring in this study led to better performance in a defined quality metric with statistically significant results.

Within these grouped metrics are more narrowly defined periods of time and process, such as those outlined and visualized by Al Kasab (2019). Telestroke programs can use these process maps to spotlight and define precise workflows for evaluation and intervention. Lee (2017) is another example of a study that used a retrospective analysis to find statistically significant reductions in “time to t-PA” within the Rush Telestroke Network. A separate retrospective analysis of the MUSC Telestroke Network patient cohort found that patients diagnosed with mild ischemic stroke (NIHSS score ≤ 5) experienced a “door to t-PA” delay of 10 min ($p = 0.007$) with approximately 15% of these patients discharged with poor functional outcomes (Harvey, 2019). The complexity of the clinical decision-making process in borderline cases caused significant delays and increased disability and is assuredly beneficial to education and intervention planning within this network. These results reveal the capacity of similar methods to meaningfully measure “door to Telestroke notification” within our subject health system, especially considering the lack of existing literature on this uniquely targeted metric based on network structure.

2.4.2 Telestroke Notification to Consult Start

Another metric uniquely fitted to this telestroke network for the purpose of program evaluation is “Telestroke notification to consult start time,” which is the next step in the telestroke process from the aforementioned measurement. After a patient enters the emergency department and the Telestroke program is notified, there is a period of time where imaging is processed and the neurologist on call is notified of a pending consult. During this time, information about the patient's disposition, medical history, and imaging is considered by the neurologist as they prepare to initiate the video consult to evaluate the patient. As Al Kasab (2019) finds, transfer times are associated with a 94 minute delay when diagnostic imaging is performed at the spoke hospital of origin prior to transfer to a thrombectomy capable center. While computed tomography angiograms (CTA) provide crucial information in the transfer decision making framework and help to avoid costly futile transfers, they are a confirmed source of delays when performed in a serial fashion and should be further studied as part of the workflow (Al Kasab, 2019). These authors identify a potential solution for this delay, which is to notify the neurointerventional team at the time of stroke code activation to justify obtaining CTA at the spoke site. Raza (2017) adds that performing a repeat CTA upon arrival at a transfer site is of low utility when patient disposition is unchanged, confirmed by a retrospective medical record review. Empirical evidence during this imaging process allows researchers to analyze spoke processes occurring in the background while the telestroke neurologist prepares to initiate the video consult.

Jagolino-Cole (2019) demonstrates that a retrospective analysis of a very similar metric, "door to page time," or the time it takes to alert the telestroke physician, can provide meaningful results. In this study, door to page times greater than 15 minutes were associated with an 8-fold increase in likelihood that door to t-PA time would be greater than 60 minutes (Jagolino-Cole, 2019). Despite variation among the spoke sites of this metric, the authors demonstrate that waiting for imaging before alerting the telestroke physician causes significant delays in treatment. Our study will address a gap in the literature that describe standards for physician altering protocols that can be used to inform future policymaking and modified regulations.

2.4.3 t-PA Treatment Rates

Just as crucial to determining the efficacy of process benchmarks within a telestroke program, such as notification times, is the measurement of t-PA rates over time. Prior to the advent of mechanical thrombectomy and the modern framework for stroke quality guidelines and regulations, t-PA was the first thrombolytic approved by the Food and Drug Administration (FDA) in 1996 to treat acute ischemic stroke. This era of stroke care focused on the number of patients that received this intravenous intervention (and how quickly) as a means of measuring the effectiveness of early telestroke programs (Wardlaw, 2014). Many found immediate success. A retrospective review of the University of Pittsburgh Medical Center's 2,588 acute stroke admissions between 2005 and 2008 demonstrated a 4% increase in t-PA treatment rate since the inception of a telestroke program (Amorim, 2013). Zhang (2018) also found that telestroke patients received t-PA at a rate of 16.6% compared to usual stroke care patients at 6.2% (95% confidence interval: 8.3, 12.0). Utilizing a propensity score matched sample allowed these authors to conclude that rural patients were still less likely to receive t-PA than their urban counterparts. Prohibitive distances and lack of bedside neurologists were again to blame.

While there is no defined GWTG or other agreed benchmark for this metric because of risk factor variation, we will compare this value over time to describe program effectiveness (Paul, 2016). t-PA treatment rate does not only provide empirical evidence for reduced mortality and disability, it also indicates the long-term cost effectiveness of a telestroke network. Weschler (2015) finds that increased t-PA rates correlate to improved outcomes and increased quality-adjusted life years along with the avoidance of the incremental costs of disability. Sonig (2016) identifies a need for further stroke awareness at rural hospitals since 4.5% of patients in the NIS database received t-PA at the transfer hospital but not at the direct admission facility. As previously stated, this can result in increased mortality and disability if the patient enters the transfer facility outside of the t-PA treatment window. The importance of measuring and disseminating this information among telestroke networks is further demonstrated by a study that measures perceived versus actual percentage of patients who receive t-PA within the 60 minute window. The results of this study by Jauch (2018) are well visualized by the authors in their Figure 2, where a mixed methods analysis during a quality improvement initiative reveals that although t-PA treatment rates increased by 3.3%, perceived rates among ED teams were on average double those of reality. This study provides a useful framework for measured education and quality improvement feedback loops that should be replicated in various regions. Patel (2019) adds to this disparity by stating that fewer than 5% of acute ischemic stroke patients receive t-PA which is attributed to lack of emergency physician experience and long distances between capable hospital facilities. Studying this metric will allow telestroke program leadership to make informed decisions on the effectiveness of their current network infrastructure.

2.4.4 Consult Volume & Program Growth

As a telestroke program grows over time, an integral measure of its ability to improve the population health of the region, along with t-PA rate, is the increase in consult volume. Increasing the value of stroke care in a region means having a well-established network algorithm that can be trusted by EMS partners that are responsible for the first point of contact with patients (Sonig, 2016). This good community and partner standing promotes value for the affected area by reducing delays to care caused by uncertain decision making. In a study of CMS administrative claims data from 2008 to 2015, Zhang (2018) found that telestroke services increased most rapidly among rural residents, from 0.6 to 8.6 per 1,000 ischemic stroke cases across the nation. It increased from 1.0 to 6.1 per 1,000 cases among super rural residents as well. This evidence of the growth in telestroke services across the United States is associated with the overall decrease of mortality and disability caused by cerebrovascular accidents.

Having a reliable and well-known network of telestroke care can also assist in monitoring other population health trends. A retrospective analysis of the Bavarian telestroke network during the COVID-19 pandemic demonstrates a significantly lower stroke incidence during periods of mandated lockdowns, which is only partially explained by reluctance to enter an emergency department (Schlachetzki, 2022). These authors theorize that the observed decrease in volume may also be attributed to lower rates of common stroke inducing infections while social distancing was enforced, but more research is required to explain this competing risk phenomenon. Awareness and education among the community are universally salient variables, outside of the parameters of a pandemic induced decrease, that improve outcomes. Arulprakash (2018) cited lack of community education in recognizing the symptoms of stroke onset as a significant cause of treatment delays in India, for example. This observational cross-sectional study is one of many that reveal preventable pre-hospital delays in neurologically underserved areas (Müller-Barna, 2012). In this context, to err is preventable by monitoring our metrics of interest.

2.5 Implementation Barriers

Persistent program evaluation ensures the constant quality improvement of a telestroke network by identifying specific points in which breakdowns occur. This monitoring system, guided by evolving evidence-based measurements and guidelines, allow healthcare leaders to preemptively consider and eliminate barriers to implementation. Gutovitz (2022) highlights several salient barriers to operationalizing teleneurology systems despite this study's lack of applicability to primary stroke centers. The authors here demonstrate that a third party teleneurology service actually further delayed door to needle times as compared to traditional bedside neurologist evaluations (64 minutes compared to 45 minutes). The question of whether or not rural and semi-rural hospitals can effectively perform NIHSS evaluations without a bedside neurologist present is still clouded by some technological unknowns. Patel (2019) deploys a systematic review to detail and summarize these obstacles, which include insufficient internet bandwidth in remote settings, trainings for front end users overseeing the virtual connection between provider and patient, consistent documentation, and interoperability between imaging and medical record networks.

Such limitations significantly reduce the perception of sustained reliability of teleneurology in certain environments and raise questions about its ability to deliver faster quality care in a cost-effective manner (Weschler, 2015). Albeit researchers have been incorporating these more sophisticated variables into their analyses over time, including Al Kasab's (2021) analysis of mean cost reduction of reduced transfer rates that is improved upon Switzer's (2013) cost effectiveness evaluation, more information is needed in varying settings. Licensing and credentialing are sometimes barriers for telestroke networks like the University of Utah Health system that span multiple states. The Federation of State Medical Boards, however, has proposed multistate compacts or proxy credentialing as potential solutions for the burden of telemedicine licensing (Weschler, 2015). A gap in knowledge persists when attempting to solve the value formula of teleneurology services (V=Q/C). Continuing to isolate and minimize sources of treatment delays in all modern programs will help to define both the numerator of quality (Q) and the denominator of cost (C).

2.6 Operationalizing Findings & Current Trends

Translating findings into meaningful process improvement requires study designs that promote an understanding of the interaction among variables in various settings. Applying this understanding using a population health lens allows for telestroke program leaders to put the patient in context. Ultimately, the motivating mission of "Time is Brain" drives all practitioners, administrators, and EMS crews alike in participating in necessary quality improvement initiatives. A telestroke program's tendency to reach many different classifications of stakeholder makes it a likely candidate for community outreach investment. Collaborating with local EMS could demonstrate more effective pre-hospital processes, for example, which may be reflected in an analysis of consult volume growth. Proactive patient and community education is also critical to success. Informal care networks have been demonstrated as effective forum for patients and their families to adapt to the realities of their newfound levels of disability (Leonard, 2022). Our health system of study has such a Stroke Recovery Program in the form of a facilitated informal network with growing popularity which can benefit from program evaluation as well.

Applying this perspective to the individual practitioner also reveals a need to understand the relationships among our own teams. A culture of trust among remote care teams must be established when building these delicate processes. These groups are often stitched together by the fate and circumstance of transfer agreements as a telestroke network takes shape across many different disciplines and functions. An understanding of the climate among the many stroke teams can enhance a statistical analysis meant to identify certain workflow inefficiencies. Qualitative assessments may be warranted in these cases, such as those conducted within the Department of Veteran's Affairs telestroke program by Patel (2021). These authors measured positive results related to the sense of shared identity and team cohesion among providers and lay the groundwork for similar studies among telestroke teams outside of the VHA infrastructure. Interoperable record and imaging systems and routine and open communication pathways will aid in creating integrative telestroke networks (Patel, 2019). Documenting the source of delays as they arise during the course of care delivery is another strategy that helps to extrapolate controllable delays in real time (Choi, 2019).

Artificial intelligence (AI) is the current technological frontier of stroke care, where it is being implemented in the form of diagnostic support to save crucial minutes in several varying points along the pathway of care (Zeleňák, 2021). Platforms with AI algorithms that can detect large vessel occlusions in CTA imaging are already demonstrating effectiveness in the field. Morey (2021) found that a computer aided triage system resulted in a median door-to-neuroendovascular team notification time interval of a significantly faster 25 minutes [IQR = 12.0] compared to 40 minutes [IQR = 61.0] ($p = 0.01$) without AI intervention. "Smart" communication and alert programs along with automated data collection are enhancing the efficiency of patient flow (Ali, 2020). As Ali (2020) so eloquently summarizes, "Despite current challenges, these synergistic technologies hold immense promise in enhancing the clinician experience, helping to reduce physician burnout while improving patient health outcomes at a lower cost."

There is great promise for telestroke and teleneurology services to meet the growing demand for advanced stroke care in our communities. Armed with the current knowledge of telestroke infrastructure strengths and weaknesses, and with further study of their impact on our localized regions, our goals for improved population health are achievable. Study designs that allow for transparent program evaluation feedback loops act as a tool for networks to safely adapt to changing clinical practices. The rise in utilization of tenecteplase, a low-cost alternative to t-PA with potentially improved outcomes, is a recent example of this methodology of quality monitoring resulting into change in practice or process (Potla, 2022). Trust and ownership of evidence-based metrics among all stakeholders in a stroke network could result in higher value care, and a descriptive analysis of metrics over time serves as an evolving baseline. We conduct this study to generate similar results as those discussed in this chapter and will monitor these measurements to continue improving the ability of health systems to deliver quality stroke care to the patient population of the Hudson Valley and beyond.

3 CHAPTER III METHODOLOGY

3.1 Research Design

This study will use a retrospective descriptive cohort design to examine trends among Hudson Valley telestroke metrics of interest as compared to quality benchmarks set by GWTG and the literature. Studies with similar objectives have successfully implemented retrospective analyses of internal data to seek out statistically significant differences in periodic performance of stroke programs. We aim to apply these lessons learned by previous researchers towards an evaluation of our own telestroke and acute stroke transfer workflows within our unique environment.

3.2 Regional Population

The patient population of the New York Hudson Valley includes residents of Westchester, Rockland, Orange, Ulster, Dutchess, Putnam, Sullivan and Delaware counties. We can ascertain from 2020 US Census Data, collected by Claritas and accessed through Sg2, that this population is projected to continue increasing by an overall 6% from 2022 to 2027. Regional population demographic data estimated from the 2022 Census, along with race and ethnicity, are shown in Tables 1-3 below. The 2022 total regional population numbers just under 2.4 million (Table 1) and includes moderate levels of racial diversity (Table 2) with just under a quarter of the population identifying with Hispanic ethnicity (Table 3).

Table 1 – 2022 and 2027 Projected Population, Hudson Valley (HV) by County

	2022		***2027***		***Change, 2022-2027***	
County	**Population**	**% of HV**	**Population**	**% of HV**	**Population**	**%**
Delaware	41,143	1.7%	42,152	1.6%	1,009	2.5%
Dutchess	310,100	12.5%	326,103	12.4%	16,003	5.2%
Orange	396,556	16.0%	421,511	16.1%	24,955	6.3%

Putnam	104,168	4.2%	109,605	4.2%	5,437	5.2%
Rockland	343,531	13.8%	364,665	13.9%	21,134	6.2%
Sullivan	80,512	3.2%	84,840	3.2%	4,328	5.4%
Ulster	195,343	7.9%	205,047	7.8%	9,704	5.0%
Westchester	1,011,195	40.7%	1,066,953	40.7%	55,758	5.5%
Total	**2,482,548**	**100.0%**	**2,620,876**	**100.0%**	**138,328**	**5.6%**

Table 2 – 2022 Population by County and Race (Alone or in Combination)

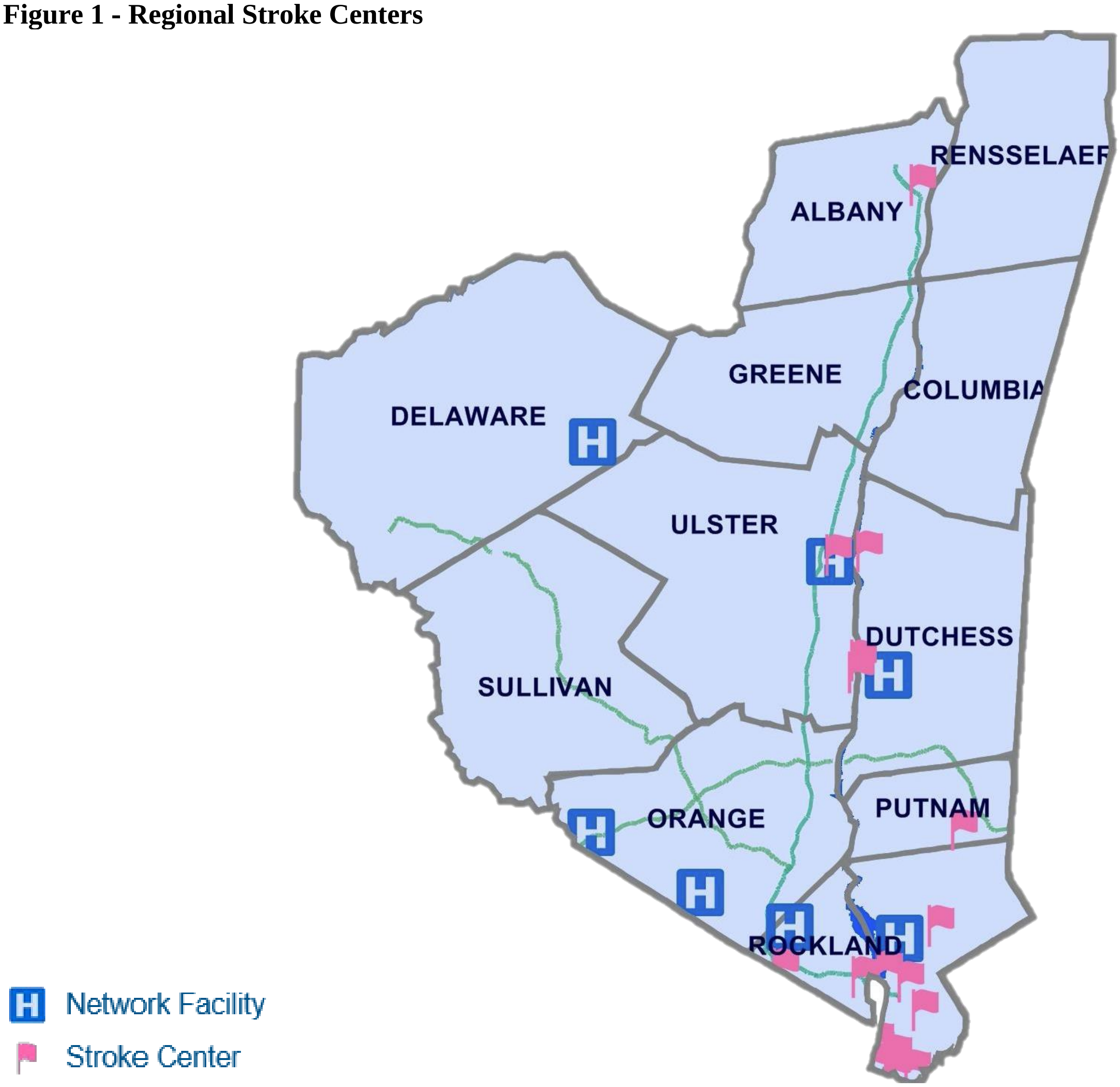
	White		***Black/African American***		***Asian***		***American Indian/AK Native***		***Native HI/PI***		***Other***	
County Name	**Pop**	**%**	**Pop**	**%**	**Pop**	**%**	**Pop**	**%**	**Pop**	**%**	**Pop**	**%**
Delaware	39,105	93.4%	1,133	2.7%	613	1.5%	411	1.0%	50	0.1%	568	1.4%
Dutchess	246,534	76.7%	41,819	13.0%	13,208	4.1%	2,975	0.9%	445	0.1%	16,288	5.1%
Orange	297,903	72.0%	57,414	13.9%	14,635	3.5%	4,995	1.2%	552	0.1%	38,228	9.2%
Putnam	93,175	86.8%	4,685	4.4%	3,060	2.9%	718	0.7%	156	0.1%	5,497	5.1%
Rockland	254,036	71.5%	46,205	13.0%	23,136	6.5%	2,340	0.7%	698	0.2%	28,696	8.1%
Sullivan	66,429	79.3%	8,916	10.6%	2,037	2.4%	1,124	1.3%	103	0.1%	5,184	6.2%
Ulster	169,770	83.8%	17,172	8.5%	5,485	2.7%	2,160	1.1%	220	0.1%	7,809	3.9%
Westchester	678,069	64.3%	169,374	16.0%	75,684	7.2%	10,575	1.0%	1,761	0.2%	119,876	11.4%
Total	**1,845,021**	**71.5%**	**346,718**	**13.4%**	**137,858**	**5.3%**	**25,298**	**1.0%**	**3,985**	**0.2%**	**222,146**	**8.6%**

Table 3 – 2022 Population by County and Ethnicity (Alone or in Combination)

	Hispanic/Latino		***Not Hispanic/Latino***	
County Name	**Pop**	**%**	**Pop**	**%**
Delaware	2,003	4.8%	39,877	95.2%
Dutchess	46,279	14.4%	274,990	85.6%
Orange	98,607	23.8%	315,120	76.2%
Putnam	20,075	18.7%	87,216	81.3%
Rockland	72,170	20.3%	282,941	79.7%
Sullivan	15,708	18.7%	68,085	81.3%
Ulster	24,912	12.3%	177,704	87.7%
Westchester	295,694	28.0%	759,645	72.0%
Total	**575,448**	**22.3%**	**2,005,578**	**77.7%**

Among the northern region (Ulster and Dutchess counties) of this community in 2019, there were 181 inpatient stroke procedures performed across all facilities in the regional market area, along with 365 treat and release Emergency Department (ED) encounters (SPARCS, 2022). The western region (Rockland, Orange, and Sullivan counties) saw 160 inpatient stroke procedures in 2019 along with 463 ED treat and release encounters. A map of the region's counties and fifteen stroke centers is included in Figure 1. The only two comprehensive stroke centers within this region are in Valhalla and Albany.

Figure 1 - Regional Stroke Centers



3.3 Cohort Selection

A cohort of all patient telestroke consults within the eight-county area within the network, regardless of transfer decision, will be used to perform this descriptive analysis. We will use the first quarter of 2020 as our beginning point in this analysis (to account for consult volume ramp up and a transition period of policies and communication workflows) and will assess data collected through the third quarter of 2022. These inclusion criteria create a cohort composed of 2,001 encounters and is selected as the only existing data for patients seen since the inception of this specific telestroke network.

3.4 Data Set Description

The telestroke network database is collected and maintained by the health system's Telestroke program and is formatted and exported into an Excel spreadsheet. This method of export is utilized as a tool for routine operational analysis, process improvement, and dashboard generation. Data for this telestroke program begin at its inception in October of 2019. These datasets are accessible to operational and program leaders upon request.

The GWTG reporting infrastructure allows for the export of configurable reports for the spoke hospital facilities within the telestroke network and are sourced by required data entry into the NYDOH registry. We utilize the "Thrombolytic Therapies" reporting measure for this analysis. GWTG allows users to compare in-network facility outcomes to other categories of regional New York hospitals to encourage the adoption of a population health lens in process improvement initiatives. We will utilize GWTG solely to collect data for our "t-PA rate" study variable.

3.5 Data Procedure

Data entries that included “unknown” or blank results for any of the study variables were excluded from this analysis. Our period of investigation is from January 2020 through September 2022 and temporal data points will be grouped quarterly by date of consult. Any associations found among the study variables will also be compared among their grouped locations to demonstrate regional impact on variables of interest.

3.6 Variables of Interest

An analysis of our study aims includes the following patient and clinical characteristics found within our databases:

1. Sex
2. Age
3. Disposition
4. Initial hospital location

Our primary and secondary outcome variables applied to our objective of determining if there are any existing relationships among the data include:

1. Door to Telestroke Notified time
2. Telestroke Notified to Consult Start time
3. t-PA Rate
4. Consult Volume

We seek to describe changes over time among the primary study outcome variables over the defined period of time since the inception of the telestroke program. The data will be grouped in quarterly segments overall and by location to demonstrate periodic results that will be used to measure which locations are showing improved results over time. These results will provide metrics to examine reach and effectiveness of the program's ability to serve our patient populations.

3.7 Data Analysis

A statistical analysis producing statistics and graphing will be performed in Microsoft Excel and our descriptive statistics will be reflected as means and standard deviations for continuous variables, and as frequencies and percentages for categorical variables. Descriptive statistics using count and percentages or means (for continuous) by quarter and location will be used to plot trends over time in our outcome variables. Regression analysis using time (quarter) as the primary independent variable will be used to assess changes in the four primary outcome variables over time. If numbers are large enough by location, then differences in time by location will also be examined using regression analysis.

3.8 Protection of Human Subjects

The health system and affiliated medical college Institutional Review Board granted approval for this study. Patient informed consent was not required, given that the data were deidentified.

4 CHAPTER IV RESULTS

4.1 Results & Findings

A total of 2,894 patients were identified within our dataset as having received a telestroke consultation from January of 2020 through September of 2022. After applying our exclusion criteria to the data, 893 visits were removed from the analysis because of incomplete data points within fields applied to this analysis, resulting in a final sample size of N=2,001. Operational notes and comments fields within the dataset, used to document anomalies in real time, reveal that missing time data points were attributed to either inpatient cases (where a patient is already in the hospital and no substitute time is noted), or improper documentation.

There are 1,099 females (54.9%) in the sample and 902 (45.1%) males. 314 (15.7%) of this cohort were between the ages of 50 and 59, with 441 (22.0%) aged from 60 to 69, 440 (22.0%) aged from 70 to 79, and 336 (16.8%) patients were between the ages of 80 and 89. There are 1,602 patients (80.1%) in this sample that were admitted to the originating hospital, while 270 (13.5%) were transferred to another facility for further intervention and treatment, with the remainder either being discharged or were already admitted during consultation. 1,325 patients (66.2%) had Telestroke consultations occur at the Site 2 emergency department, with Site 1 hosting 427 (21.3%) of total consultations. Site characteristics and metrics are important to understand locational trends, however sites 3 through 5 remain relatively new to the program.

Table 4 – Population demographic and Emergency Department visit characteristics of patients indicated for a Telestroke consultation within this network.

Clinical and Patient Characteristic	Telestroke Consultations n= 2,001
Sex	
Male	902 (45.1)
Female	1,099 (54.9)

Age	
≤29	57 (2.8)
30-39	96 (4.8)
40-49	189 (9.4)
50-59	314 (15.7)
60-69	441 (22.0)
70-79	440 (22.0)
80-89	336 (16.8)
≥90	128 (6.4)
Disposition[a]	
Admitted	1,602 (80.1)
Transfer	270 (13.5)
Discharged	123 (6.1)
Inpatient	6 (0.3)
Initial Location[b]	
Site 1	427 (21.3)
Site 2	1,325 (66.2)
Site 3	45 (2.2)
Site 4	181 (9.0)
Site 5	23 (1.1)

All values expressed as n (%)

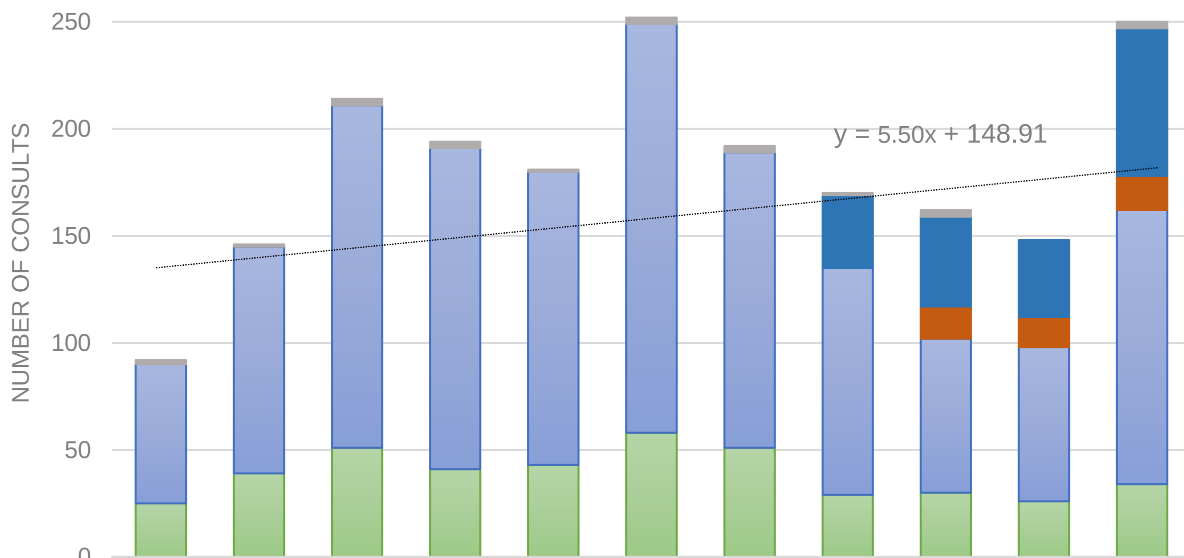
[a] A variable that indicates the treatment decision for a patient after the conclusion of the telestroke consultation.

[b] A variable that indicates the hospital location in which a patient initially enters the Emergency Department.

4.2 Consult Volume

Overall consultation volume within this Telestroke network is shown in Figure 2. While the trend is not perfectly linear, the slope of the fitted linear regression line on consult volume indicates that volume grew on average by 5.5 consults per quarter (p=0.0007). This suggests a statistically significant increasing trend in consult volume that is greater than zero as the program ages. Portraying volume by site in this manner is intended for quality improvement projects to highlight focal points for assigning resources as needed. Overall, the significance of the addition of new sites to the network is noted, such as in Q4 of 2021 (Site 4 added) and Q1 of 2022 (Site 3 added). Trend lines indicate that as new sites join the program there is a temporary worsening of metrics with high variation prior to returning to more consistent estimates. The effect of site volume on our time metrics is examined below to further our understanding of the relationships between these variables of study and their impact on patient care.

Figure 2 – Telestroke Consult Volume by Location



	20 Q1	20 Q2	20 Q3	20 Q4	21 Q1	21 Q2	21 Q3	21 Q4	22 Q1	22 Q2	22 Q3
Site 5	2	1	3	3	1	3	3	1	3	0	3
Site 4								34	42	36	69
Site 3									15	14	16
Site 2	65	106	160	150	137	191	138	106	72	72	128
Site 1	25	39	51	41	43	58	51	29	30	26	34

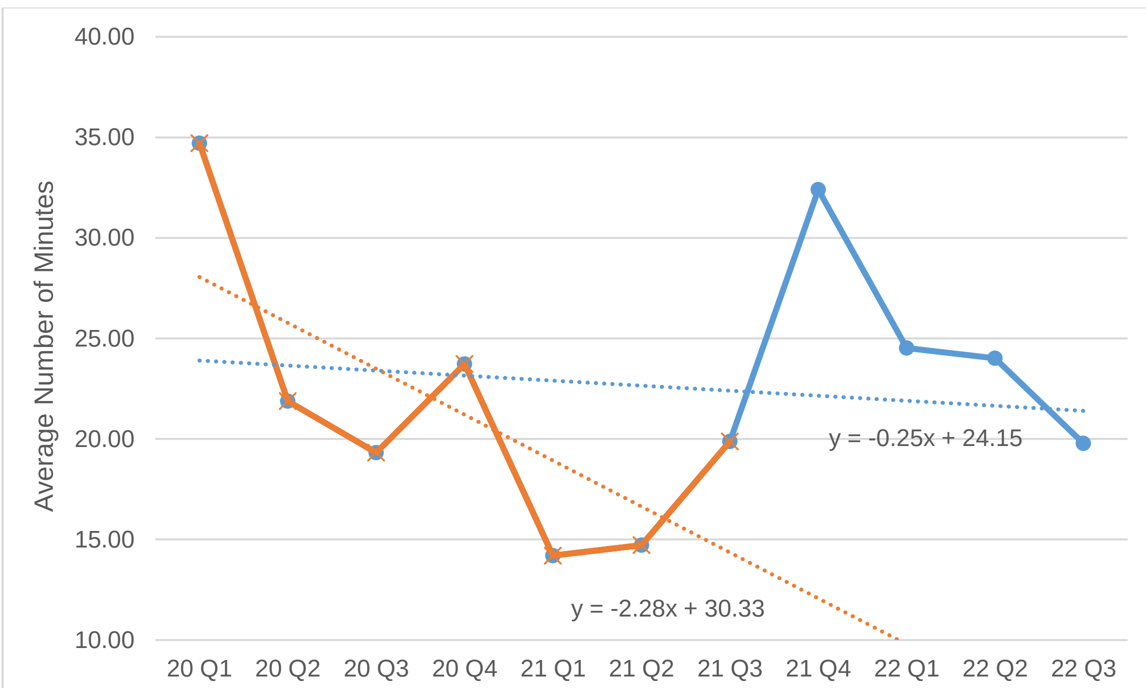
4.3 Time Metrics

The time metrics are each visualized in three different figures to better examine the study relationships of interest and to understand the variation among them over time. This method facilitates the use of varying lenses of magnification when evaluating a telestroke program, and better guides the allocation of process improvement resources.

4.3.1 Door to Telestroke Notification

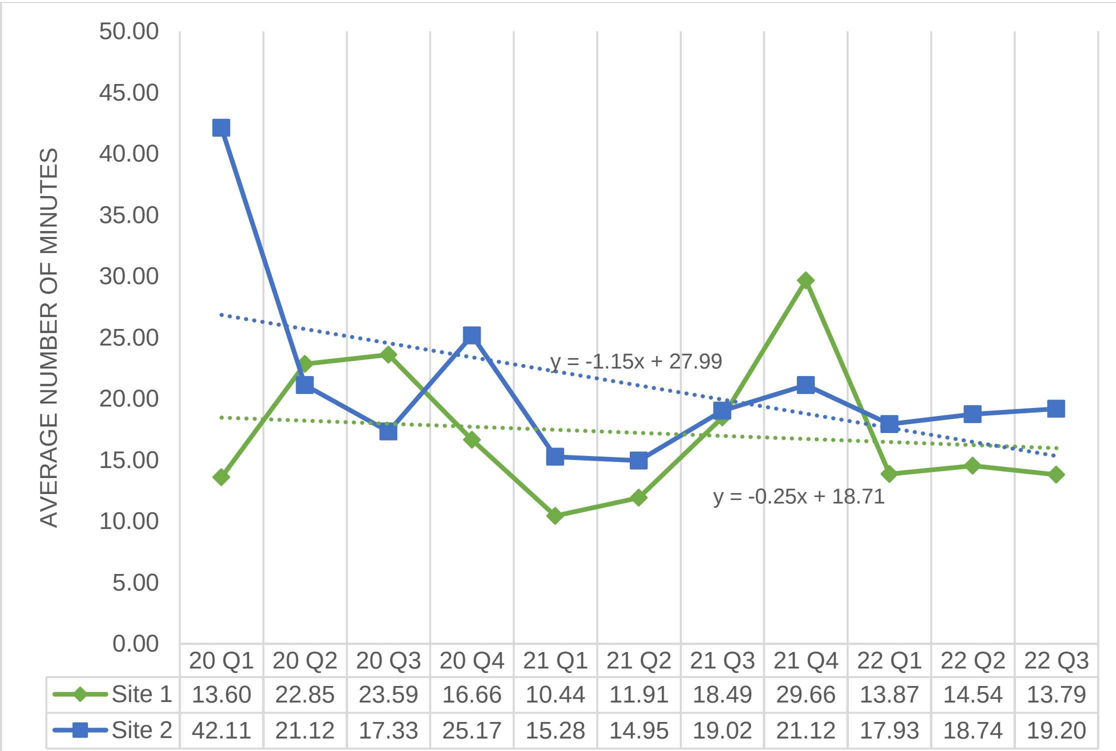
Overall Door to Telestroke Time in Figure 3 includes a line graph by quarter of network average over the entire period of study with the orange portion of the line showing the trend prior to the addition of two new sites. The mean Door to Telestroke Time at the start of the study period (34.7 minutes) decreased by 43% to a mean of 19.8 minutes by Q3 of 2022. Over the first seven quarters, the average door to Telestroke time decreases by a statistically significant 2.28 minutes per quarter (p=0.001). Temporary increased time from door to Telestroke notification after onboarding new sites is evident after the seventh quarter. The impact of new site "learning curves" significantly worsen earlier trends (0.25 minute decrease, p=0.0003) but seem to begin to return to prior averages within four quarters.

Figure 3 – Total Average Door to Telestroke Notification Time



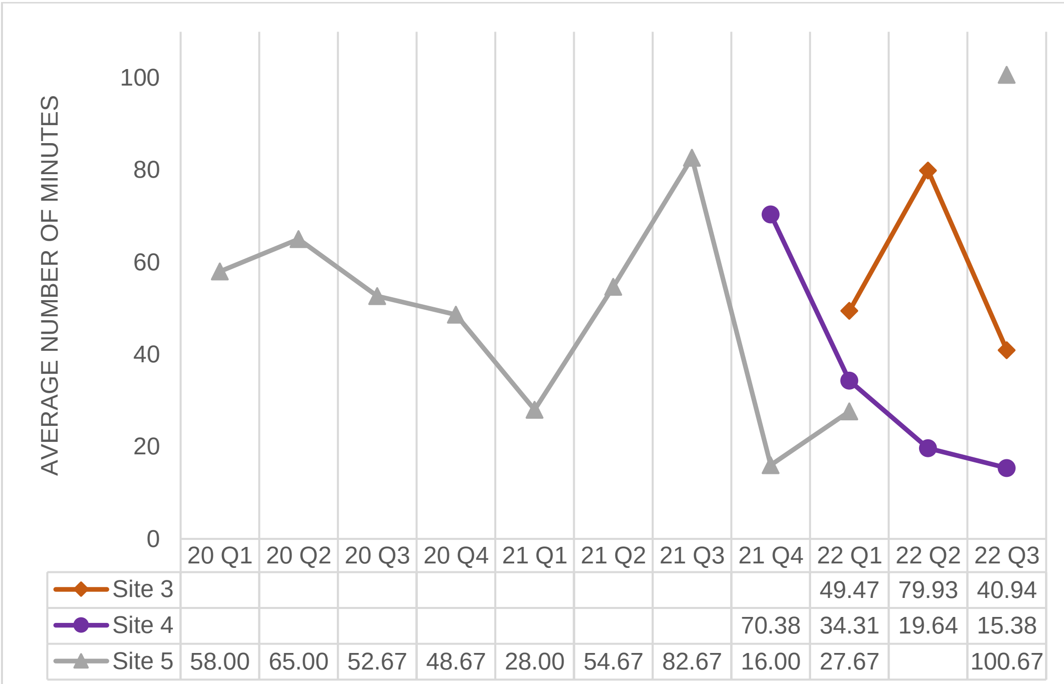
An examination of Sites 1 and 2 is shown in Figure 4, which demonstrates the trends within this metric at the two most longstanding sites in the program that drive the total network average. Over the entire period of study at Site 1, the average door to Telestroke time decreases by 0.25 minutes per quarter. At Site 2, the average door to Telestroke time decreases by 1.15 minutes per quarter. A temporary increased average time from door to Telestroke notification after onboarding new unassociated sites is apparent even at Sites 1 and 2 after the seventh quarter. There is a discernable improvement in average Door to Telestroke Notification Times over time despite the variation generated by program expansion.

Figure 4 – Average Door to Telestroke Notification Time (Sites 1 and 2)



As we seek to understand any variation among the remaining sites, we use Figure 5 to further examine the effect of onboarding. Site 5 is a longstanding site similar to Sites 1 and 2, but with significantly lower consult volume. Even at this low volume location, Site 5 experienced demonstrative variation prior to the onboarding of Sites 3 and 4. Site 4 displays a consistent downward trend and improvement within this metric over four quarters. Alternatively, Site 3 shows inconsistent average Door to Telestroke Notification times during its relatively short participation within the program. Over this span, it is undetermined whether there is an improvement in this metric over time at Sites 3 through 5.

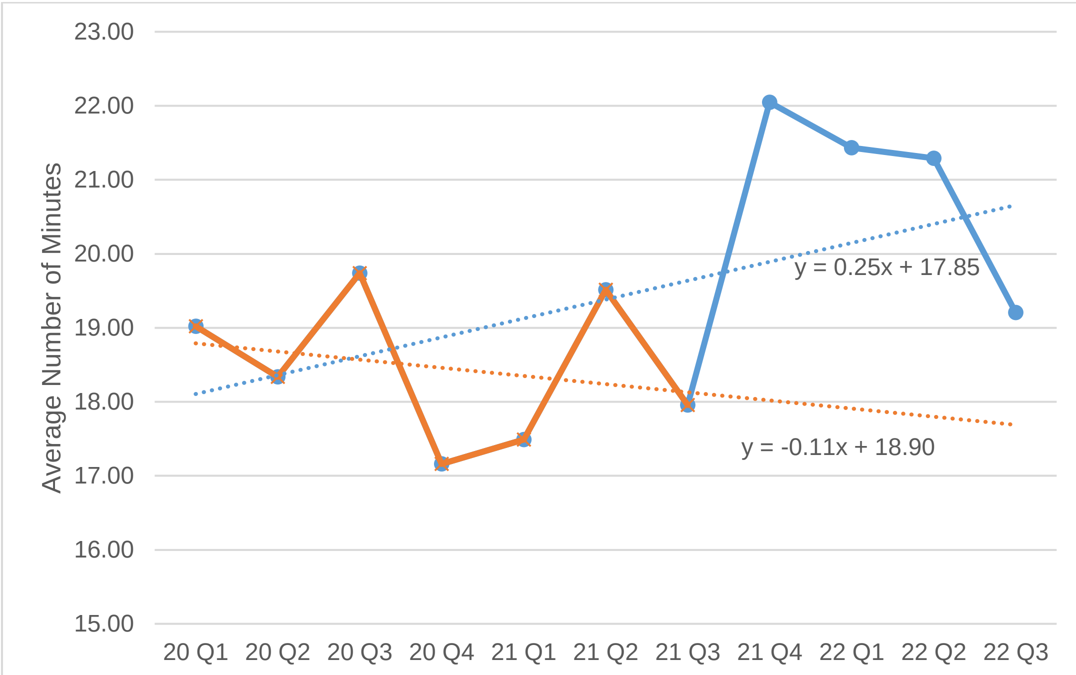
Figure 5 – Average Door to Telestroke Notification Time (Sites 3, 4, and 5)



4.3.2 Telestroke Notified to Consult Start

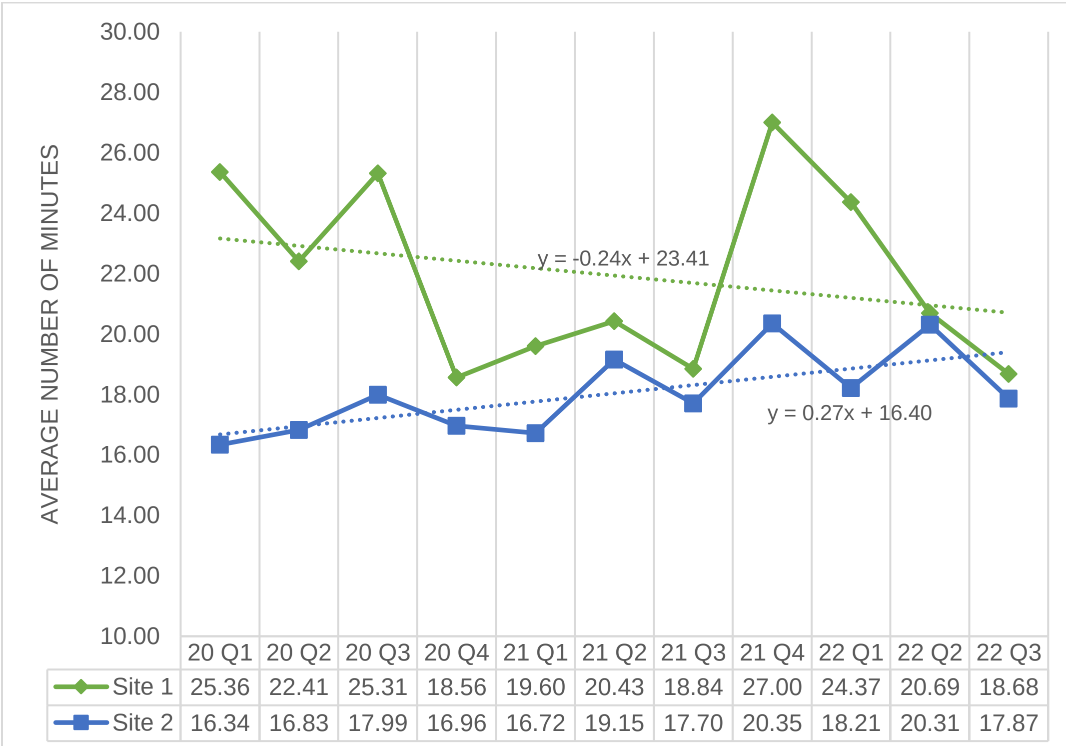
The second time metric of Telestroke Notified to Consult Start Time examines the impact of consult volume on the overall program structure's capacity to respond efficiently. Figure 6 includes a line graph by quarter of network average over the entire period of study with the orange portion of the line showing the trend prior to the addition of two new sites. The average Telestroke notified to consult start time decreases by a statistically significant 0.11 minutes per quarter over the first seven quarters ($p<0.001$). Albeit over the entire period of study the average Telestroke notified to consult start time increases by a statistically significant 0.25 minutes per quarter ($p<0.001$). These trends show a greater than zero reduction in response time until the sudden increase of new site volume reduces the effectiveness of the network infrastructure.

Figure 6 – Average Telestroke Notified to Consult Start Time (Network Total)



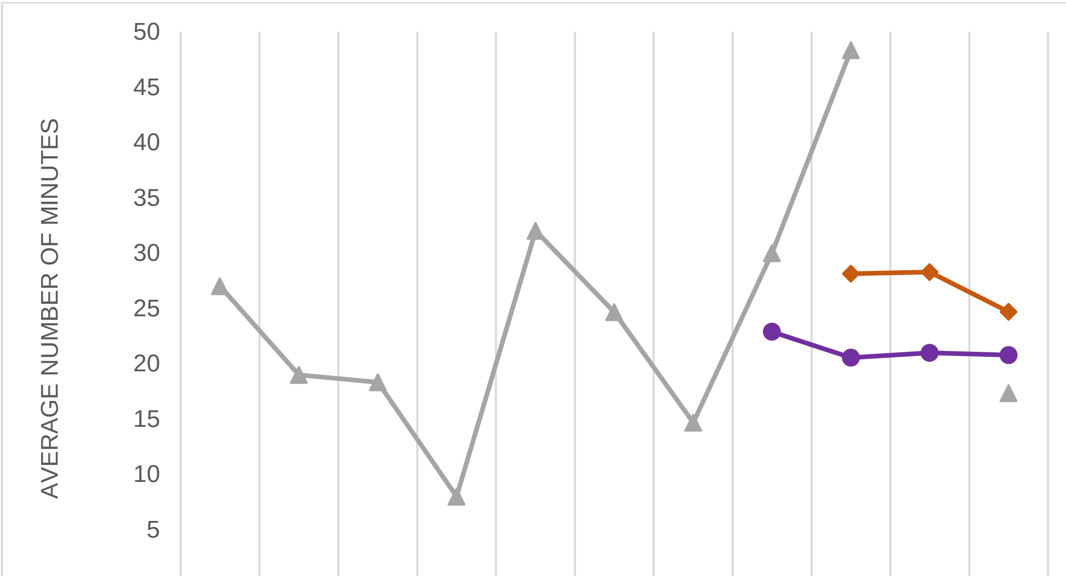
Trends in average Telestroke Notified to Consult Start Time at Sites 1 and 2 can be seen in Figure 7. At Site 1, the average time from Telestroke notification to consult start decreases by 0.25 minutes per quarter, denoting a progressive improvement with transitory variation during the onboarding of new sites. At Site 2, the average door to Telestroke time increases by 0.27 minutes per quarter with low variation. There is a detectable improvement in average Telestroke Notified to Consult Start times over time at Site 1 despite high variation, but the opposite effect is observed at Site 2 with consistency in a relatively tight range. Further examination is required to understand factors contributing to these locational trends.

Figure 7 – Average Telestroke Notified to Consult Start Time (Sites 1 and 2)



As captured in Figure 8, Site 5 experiences dramatic variation in average Telestroke notified to consult start times among a small sample size. Sites 3 and 4 show minimal variation during their respective periods of participation in the network. These figures exhibit the relationship between overall consultation volume within the network and are a useful tool in revealing trends that require further evaluation. For example, it appears that low volume sites have, on average, higher Telestroke notified to consult start times when compared to high volume sites. However, it is undetermined whether the length of time in the program improves Door to Telestroke Time or Telestroke Notified to Consult Start Time.

Figure 8 – Average Telestroke Notified to Consult Start Time (Sites 3, 4, and 5)

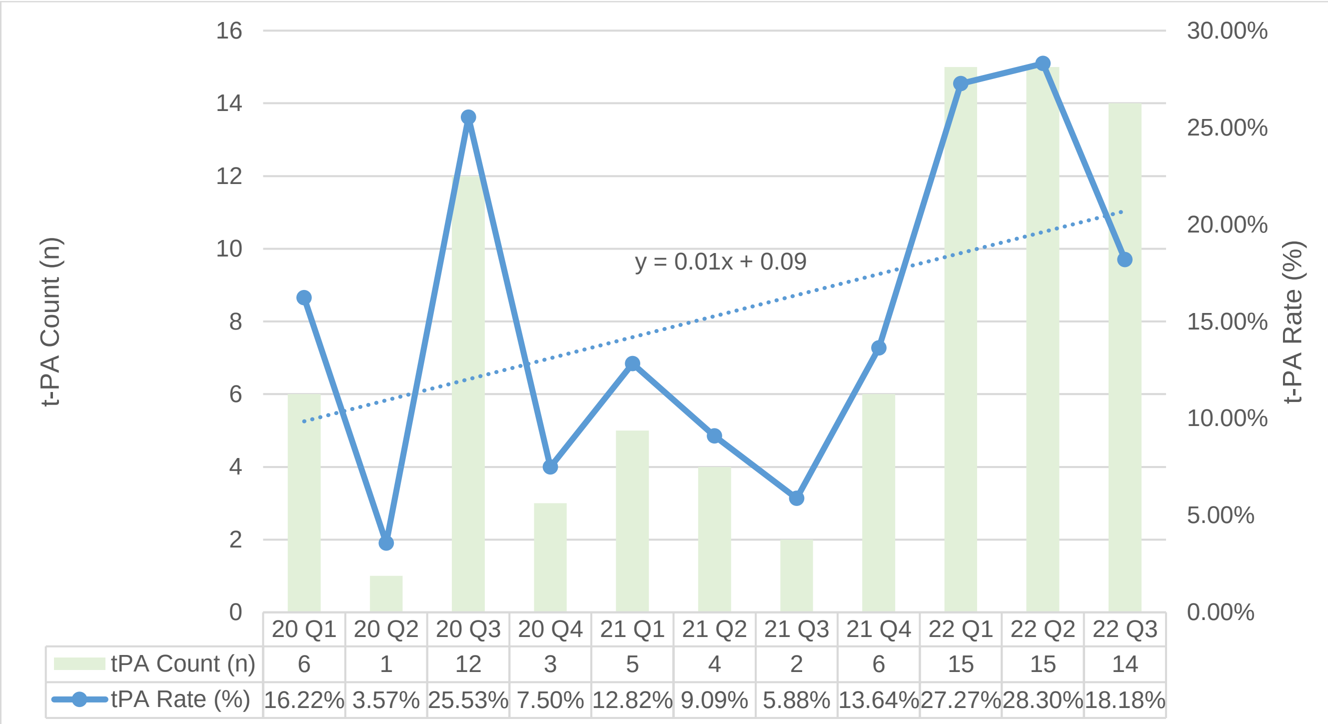


	20 Q1	20 Q2	20 Q3	20 Q4	21 Q1	21 Q2	21 Q3	21 Q4	22 Q1	22 Q2	22 Q3
Site 3									28.13	28.29	24.69
Site 4								22.88	20.55	20.97	20.77
Site 5	27.00	19.00	18.33	8.00	32.00	24.67	14.67	30.00	48.33		17.33

4.4 t-PA Rate

Trends in t-PA Rate can be seen in Figure 9, where this quality of care metric is used to determine the percentage and volume of patients that receive this lifesaving antithrombotic agent. t-PA volume and rates at Sites 4 and 5, combined to generate a more robust view of the data among the sites with accessible data, demonstrate that the rate increases on average by 1.1% per quarter, but this slope is not significantly greater than zero (p=0.44). The sparse data in this context do not allow for any further statistical comparisons or conclusions but instead serve as a template for further data collection and study.

Figure 9 – t-PA Rate at Sites 4 and 5 Combined



5 CHAPTER V DISCUSSION

5.1 Discussion of Results

The role of process improvement in serving the mission of delivering timely Telestroke care cannot be understated. Clouds of fundamental variables that influence timely care form a complex system, however these often elude accurate measurement. This study seeks to inform the design of frameworks in which to monitor and understand the variation and relationships among these challenging variables as we strive to save 1.9 million neurons per minute. Telestroke consultation volume across sites is analyzed to provide valuable context as we ask whether the Telestroke network results in a reduction in the Door to Telestroke Notification or Telestroke Notification to Consult Start metrics over time. An assessment of t-PA rate, a secondary indicator for overall program quality, diversifies not only this performance evaluation, but also recommendations for a true surveillance system.

5.1.1 The Implication of Program Growth

An upward trend in consult volume reveals programmatic growth by an average 5.5 consults per quarter. This steady growth signals an increasing reach into and integration with rural and semi-rural communities that may not have previously had access to any neurological care. Such progress in addressing the needs of this patient population may also serve as a foundation for further expansion of other teleneurology (or telemedicine) services as needed. MUSC is one such example of a health system that successfully expanded teleneurology services by leaning on the established infrastructure of a successful Telestroke program. These are value-forward efforts in improving outcomes and reducing long term disability as we seek to treat patients in their local environments.

In evaluating the capacity of the program infrastructure to efficiently absorb additional volume, whether fueled organically or by the strategic addition of spoke sites, we also seek to understand any corresponding variation within our quality time metrics. Sustainable growth is an objective for this program that can be related directly to our quality metrics studied here. Sudden increases in volume may quickly become unsustainable if there are not enough resources to accommodate additional demand. Temporary yet intensive additional responsibilities for a new spoke site onboarding process, for example, include onsite and remote staff training and education, drafting and approval of new protocols and implementation plans, and redesigned IT support systems. There is also an adjustment period for new sites to acclimate to these new protocols that must be accounted for. The variation associated with the addition of new sites, as evidenced by the onboarding of Sites 3 and 4, means that proactive allocation of additional resources is required to prepare for these events. To err is predictable with a true monitoring system that defines both historical trends and future opportunities. Additionally, it is understandable that within sites having lower volume it may take a longer period of time to fully integrate and optimize a new process since that process is more sporadically needed than at high volume sites.

5.1.2 Spoke Site Response Time

The overall network mean Door to Telestroke Time decreased by 43% from 34.7 minutes to 19.8 minutes, with a linear regression line exhibiting a decrease of an average 0.25 minutes per quarter. At first glance, these results indicate a program that can support its individual sites in marginally effective process improvement over time. The analysis of consult volume by location, however, identifies a certain period of time in which two additional sites joined the network, adding a predictable strain on existing network support structures and possibly causing variation within the time metrics. This variation manifested within two separate methods of visualizing the trends within this metric.

First, during only the period prior to the onboarding of Sites 3 and 4, a regression analysis reveals a more effective network total decrease of an average 2.28 minutes per quarter. Both network total slopes reveal a downward trend in this metric, with a varying degree of improvement based on the site load of the total program. Second, when analyzing Door to Telestroke Time by location, more variation is found within the newly onboarded and low volume sites that initially may take more time to learn and transition workflows. Regression lines of Sites 1 and 2, the locations driving the total network average, reveal respective 0.25 minute and 1.15 minute average decreases per quarter in this metric. There is preliminary evidence to substantiate an improvement of this metric over the course of time participating in this Telestroke network given that resources are accurately distributed towards identified areas of opportunity as needed. Studies that measure similarly bespoke metrics also generate an understanding of unique variables that result in meaningful intervention design and implementation. It is important to also recognize that once a site has fully integrated a new program and optimized their process, their times may level off as there is likely a floor effect where sites cannot further reduce time.

5.1.3 Telestroke Response Time

The analysis of the second time metric of Telestroke Notified to Consult Start reveals a deeper narrative of the total network consult volume’s impact on the program structure’s capacity and efficiency. A linear regression line of the network total depicts an unexpected upward trend of an average 0.26 minutes per quarter. A regression line of only the period prior to the addition of new sites reveals a downward trend of an average 0.11 minutes per quarter. The impact of additional site onboarding is depicted within this metric and begins to highlight weaknesses within the capacity of the core infrastructure of the program. In this context, dichotomous benchmarks such as a percentage of consults under a defined number of minutes may allow us to interpret the data with more varied indicators.

As noted in the literature, this is a point in the Telestroke process in which technological barriers such as EMR and imaging interoperability, communication systems and protocols, and point of care internet bandwidth come into play and all must be thoroughly considered as a cause for delays in care shown by these trends. Quantifying the consequence of delays, such as Jagolino-Cole's (2019) evidence of an eight-fold increase in the likelihood that door to t-PA times would be more than one hour if door to notification times were greater than 15 minutes, serves as a powerfully transparent educational tool.

A location specific analysis exhibits that Site 1 improves by an average 0.25 minutes by quarter with high variation, whereas Site 2 increases by an average 0.27 minutes per quarter, albeit within a tighter range. Site 2's persistent increase serves as a trigger for further analysis to define the drivers behind a slowly increasing average. Potential reasons for this upward trend in response time include Telestroke cart technological issues or inefficient activation workflows and protocols at Site 2. This particular result exemplifies the kind of alarming trend that monitoring systems seek to isolate. High variation among the low volume Site 5, which also displays an upward trend, is another trigger for further investigation. The remaining sites demonstrate more consistent, albeit brief, outcomes and should be further monitored without action. The evidence generated by this descriptive analysis indicate that the onboarding of new sites is a resource intensive task that should be planned proactively and extensively. These analyses will also aide in the initiation of uniquely targeted process improvement projects and the design of a true monitoring system within this network and hopefully in others.

5.1.4 t-PA & Overall Quality

Quality stroke care also means swift and effective decision making once a patient is presented. Time metrics as described in this study fit the unique workflows related to this specific Telestroke network, but a detail not lost within the process is the clinical decision to administer t-PA. As 80% of acute stroke cases are ischemic, the same percentage of patients may qualify for this life saving drug. t-PA rate is therefore an effective means of evaluating a program's ability to diagnose and administer within the standardized window of treatment. In this analysis, the sparse volume at the two sites with accessible t-PA data were combined to better visualize any trends within this metric. With high variation and low volume, there is an average 1.1% quarterly increase, which demonstrates this indicator's value as a tool to help understand variation within a larger monitoring system. Team education and clinical protocols can be further adjusted if any negative trends are found in the future when access and volume increase over time to develop more substantial data. Future results can also be compared to benchmarks set by the literature, which range from an average 4% to 17% increase in t-PA rate over time with even greater rates cited internationally (Kawano, 2016).

5.2 Practice & Policy Recommendations

While some adverse short-term trends exist within our results, we posit that the long-term predictive capability of this descriptive analysis, along with concerted process improvement efforts, will demonstrate continued operational efficiencies until a steady state is reached. This baseline analysis will serve as the framework upon which the program can develop a true monitoring system. We have learned that it is possible to identify and understand trends by location, and will work towards devoting resources to identified areas of need in the quest to continually improve patient outcomes. With this objective in mind, it is prudent to integrate the metrics studied here into a quality dashboard that is systematically monitored and evaluated quarterly. Baseline data from this analysis can be applied towards the development of programmatic specific benchmarks and targets over time alongside established industry standard metrics. A review of metrics can also catalyze proactive project management cycles when new sites are planned, for example. Several other practical recommendations apply to this Telestroke network (and others) that extend beyond quality monitoring.

Perhaps most salient in this methodology is the goal of instilling a sense of ownership, stewardship, and trust of these metrics and data among our teams. The utility of open feedback loops with EMS providers, ED teams at spoke sites, and the neurologists themselves lies within real-time process improvement akin to Toyota's "quality circles" of lore. Quantitative data only informs as to the topic of study, whereas the perceptions and feedback of team members completes the story. Imbuing a network culture with a sense of self-efficacy and an emotional connection to the Time is Brain mantra means transparent quantification of quality efforts in juxtaposition to the consequence of delays. A systematic dissemination of results and collection of input can encourage an open system that better motivates targeted interventions with clear objectives. Goal Setting Theory as detailed by Perreira (2019) and Scott & Davis (2006) provides further context for designing such targets.

Some of these actionable interventions may include a gap analysis of the current

Telestroke platform and overall program structure, followed by a vendor assessment for alternative options if baseline performance is not satisfactory. A process map of communication pathways and educational needs by site will aide in developing more standardized and efficient protocols across the network. Listening to stroke teams can determine the need for a dedicated IT support line for Telestroke equipment. A time series analysis of consult density by day and time will also help to develop a better understanding of periodic demand on the system and can inform staffing coverage schedules. Opportunity analyses for HRSA rural health network grants would even secure funding for much of these efforts. As evidenced by this sampling alone, operationalizing solutions can be as simple as developing a printed point of care IT troubleshooting checklist, or as advanced as implementing an agile Telestroke physician staffing model based on forecasted hourly demand. Yet none can be achieved without data, an engaged team, and a clear mandate to move forward. It is important to note that a consistent data collection system is key to a full view of the process. In this project we had a loss of 31% of the original consults due to missing or erroneous data, with only a small fraction of the remaining consults having t-PA data.

Through the lens of population health, Telestroke systems should be well celebrated by policymakers as a model for value-based care. The tangible focus on timely care, which can be substituted for other formulaic variables by specialty, directly impacts outcomes and the level of costly long-term disability. An increasing prevalence of neurological conditions is also notably compounded by persistent inequities in rural care. The power of public opinion and demand for these services and the evidence-based success of systems of care such as Telestroke networks have opened the window for continued policy advancement and a review of reimbursement policies. The Rural Health Innovation Act of 2021 (S.2450) exemplifies legislative efforts in this field that require a groundswell of support in order to pass into actionable policy. This study will be succeeded by localized advocacy efforts aimed at promoting access to rural care, bringing attention to prevention and wellness tactics, and promoting health literacy.

5.3 Limitations

Limitations in sample size in Site 5 and among the t-PA data are noted as impacting the internal and external validity of this analysis. The reliability of free-text documentation may also compromise internal validity and should be further evaluated as a component of the data collection tool. Despite these shortcomings, there is still utility in this descriptive analysis as a generalizable framework for future study and practical intervention.

5.4 Future Research

This descriptive analysis has established a framework for the creation of a performance monitoring system using unique metrics that fit the organizational structure. These results can serve as a baseline for future pilot projects and interventions that measure outcomes and variation before and after implementation of programmatic changes over a longer period of time. Some possible interventions include a change in Telestroke platform or the transition from t-PA to tenecteplase (TNK). In these cases, mixed methods study designs should be considered to qualitatively measure perceptions among staff to encourage engagement, pinpoint process weaknesses, and to define shortcuts that arise within workflows. This qualitative component will naturally complement the concept of feedback loops and create an open system that promotes trust and ownership. The effectiveness of these continuous feedback loops can even be qualitatively studied independently in a similar design used by Jauch (2018) that compares perceived versus actual outcomes to encourage further transparency. The timing of such quality improvement efforts can also be compared to variation within the established monitoring system.

Other research that may add to the base of knowledge in this field include topics such as the expanded use of teleneurology alongside Telestroke for follow up or preventive care. There is also a dearth of literature on the cost effectiveness of varying Telestroke physician staffing and coverage models. A cost-utility analysis of the "Reasons for Transfer to Higher Level of Care" metric within GWTG would serve as a useful economic indicator as well. To continue the thread of promoting value within our system, the extended cost effectiveness of t-PA versus increased use of TNK related to reduced disability and increased quality adjusted life years (QUALYs) would help to set a modern industry standard (Wechsler, 2015). Finally, a multidisciplinary approach to stroke care should always be considered as science continues to unveil the hidden interactions within our own biological systems that have significant implications when translating evidence-based research into practice (Tiedt, 2022).

5.5 Conclusions

The mission to continuously improve our ability to preserve brain tissue in acute stroke patients by reducing the time to treatment is accomplished through constant program monitoring and process improvement. It is undetermined whether time within this network of study results in improved performance of designated metrics, yet further research over longer periods of time will produce meaningful evidence that should be thoughtfully translated into practice. There is a clear mandate to proceed with the design and transparent dissemination of bespoke performance indicators alongside industry standard benchmarks as a means of promoting engagement and self-efficacy within our care teams.

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