A Practical Guide to Implementing AI in Telestroke Networks

Brett C. Meyer, MD,[1] Melissa Mortin, MS, APRN, ANP-BC, ANVP-BC,[1] Lovella Hailey, MS, APRN, ANP-BC,[1] Carla Wood, DO,[2] Reza Bavarsad, MD, FAHA,[1] Kunal Agrawal, MD,[1] Royya Modir, MD,[1] Thomas Hemmen, MD, PhD, FAHA,[1] Dawn Meyer, PhD, FNP-C, ANVP-BC, FAHA[1]

Abstract

Stroke systems of care have been developed over many decades. Refinement of these care pathways has been driven by the need to quickly evaluate patients for thrombolytics or thrombectomy. With the development of reliable artificial intelligence (AI) algorithms, the use of AI in stroke pathways has become more widely utilized. Systems of care have pivoted to incorporate this technology to optimize the systems of stroke care and improve patient outcomes. Telestroke networks have exponentially increased over the past two decades and have now become a standard means of caring for stroke patients when immediate stroke care is not available at bedside. Though AI tools may be incorporated into many telestroke networks, assessing how to implement these technologies into the telestroke landscape has been limited. In this manuscript, we aim to discuss the use of AI in telestroke workflows with emphasis on different platforms, technology and infrastructure requirements, clinical workflow considerations, and use within the transfer processes. Our aim is to detail the critical factors which may come into play during telestroke AI platform implementation, deployment, and use of this rapidly expanding telestroke tool.

Keywords: Telestroke, artificial intelligence, networks, stroke thrombolytics, neurointervention.

Telestroke Background

Telemedicine refers to the use of telecommunications technology as applied to the remote evaluation, diagnosis, or treatment of a patient. Telestroke has been in use since at least the early 2000s with its use escalating over time.[1,2] The overall purpose of acute telestroke is the assessment of patients for hyperacute treatments such as thrombolytic therapy, thrombectomy, or intraparenchymal hemorrhage treatment at institutions that may not have immediate access to that expertise. As telestroke programs have evolved, the evidence supporting telestroke use is now widely available in the literature.[3] Thrombolytic therapy is only administered to a small percentage of acute stroke patients in large part due to geographic barriers.[4-8] As telestroke can solve for some of these geographic barriers, coupled with its proven reliability and efficacy in acute stroke medical decision-making, telestroke enabled care will likely be in standard practice for years to come.[3,9]

Telestroke Networks

Telestroke networks often include both a hub stroke center providing the telestroke expertise and a spoke stroke center where the patient is physically located. Telemedicine systems consisting of a video and audio source for two-way communication are deployed to these spoke centers to allow Health Information Portability and Accountability Act (HIPAA) compliant audio and video communications with stroke experts located some distance away from the patient. If thrombolytic therapy is administered at the spoke, patients can either stay at their spoke facility or be transferred in the "drip/bolus and ship" model to the hub or partner center for further care.[10,11] Now that neurointerventional options exist both for the standard window and the extended 0-24 hour window,[12-16] this "drip/bolus and ship" method becomes even more critical for telestroke specialists evaluating patients for acute therapies.[17] Final determination regarding transfer needs depends on the type of hospital system and type of telestroke network in place. Networks can be "open", where a central telestroke group provides care to many different hospitals, or "closed" where all spokes are within the same hospital system. Both types of systems require strong clinical and transfer workflows to be in place to ensure that delays are minimized. The closed system generally establishes a hub center within their network to access transfers from their spokes based on geographic proximity. Telestroke providers usually staff these spoke hospitals virtually during the acute stroke time window for consideration of acute thrombolytic or consideration of embolectomy in the standard time window (0-6 hours).[12-14] The extended window for neurointerventional procedures has expanded to 0-24 hours when a core-perfusion mismatch is noted on acute stroke radiographic imaging. AI plays a critical role in assessing for both large vessel occlusion (LVO) and penumbra to core mismatch on imaging.

Telestroke AI

Since the completion of two pivotal trials in neurointerventional therapy for stroke, the implementation of AI has become integral to the care of stroke patients in a telestroke workflow.[15,16] DEFUSE-3 published landmark thresholds for penumbra-core mismatch in the extended treatment window (0-24 hours) that might predict salvageable brain tissue if the patient is taken to embolectomy.[16] Clinically important values may include (1) Ischemic core volume <70 mL, (2) ischemic penumbra volume < 100 ml, and (3) ratio of penumbra to core > 1.8. Favorable values may potentially predict thrombectomy benefit.[15,16,18]

AI vendors may use proprietary algorithms to determine presence of LVO and determine degree of perfusion mismatch on advanced neuroimaging such as computed tomography perfusion (CTP) or magnetic resonance imaging perfusion (MRP). Vendors may provide summary screens showing presence of an LVO or relevant ratios for prediction of salvageable tissue. Some vendors have additional features embedded within or in addition to their core platforms including automated detection of Alberta Stroke Program Early CT Score (ASPECTS), intracerebral hemorrhage (ICH) detection, aneurysm assessment, collateral scoring, 3D reconstruction, rotation, and the ability to re-calculate perfusion curves.

Determination of potentially salvageable brain tissue for potential thrombectomy patients becomes extraordinarily relevant for telestroke. Telestroke networks have had to adapt to this new data showing potential benefit for thrombectomy even out to 24 hours. Telestroke specialists are now routinely evaluating patients not only in the 0-3 hour window, but 8x more coverage based on the time window alone.

There are many AI vendors in the telestroke landscape, with the list continually growing. RapidAI (formerly iSchemaView; Menlo Park, CA, USA) is one of many AI platforms used for the identification of LVO, mismatch on CTP and MRP, ICH, and ASPECTS.[19] This platform has been utilized in several clinical trials assessing for possible endovascular therapy appropriateness to date. Viz.ai (San Francisco, CA, USA) also focusses on acute stroke with their flagship product Viz-LVO.[20] They also have a proprietary algorithm which shows presence of LVO and core to penumbra mismatch data, focusing on CT, computed tomography angiography (CTA), and CTP pathways instead of MRI. This vendor also utilizes their communication tools to leverage improved communication between the stroke team and electrophysiology or interventional cardiology teams in later phases stroke management. Aidoc (Tel Aviv, Israel) is another vendor focusing on stroke specific abnormality detection in the acute evaluation pathway.[21] Their tool also helps radiologists prioritize image evaluation using AI algorithms. Brainomix (Oxford, United Kingdom) has also developed proprietary AI algorithms to help guide treatment and transfer decisions for stroke patients.[22] There are at least 18 United States FDA-approved AI technology companies in the stroke diagnosis and management arena.[23] A detailed overview of each company is beyond the scope of this manuscript. Providers and hospital systems should critically evaluate each vendor for technology, reliability, service, and particular use case required.

Technology and Infrastructure

Although the AI vendor partner often drives the technology and infrastructure implementation, a few critical elements should be considered before implementation. The most fundamental requirement driving both the clinical assessment and technology choice is the AI algorithm assessment of LVO and core to penumbra mismatch. Due to the remote nature of telestroke there is a critical need for image transmission from spoke to hub for clinical interpretation. This is a core process in telestroke irrespective of AI since the provider needs to ascertain whether there is a hemorrhagic contraindication noted on noncontrast head CT.[24] In AI assisted telestroke, there is an additional need to send those images to a vendor-specific AI server for processing. Image transmission pathways to the AI server can take the form of a virtual private network (VPN) or other similar solution (Figure 1). Specific scanning protocols are encouraged for the appropriate AI algorithms to be applied. Spoke facilities may be under resourced compared to hub facilities and may have CT scanner technology but not the staffing or equipment resources to obtain hyperacute MRI scans in stroke. As such, in telestroke we may note AI applied to CT scans. Algorithms applied to the acute brain imaging do not take long to process and then are transmitted to their final destination in only a few minutes. After being sent from the spoke scanner to the AI server for application of the proprietary algorithm, these scans can be sent to the hub either to a desktop accessible Picture Archiving and Communication System (PACS) or a mobile smart-phone for near-immediate mobile image access (Figure 1). An automatic send feature on the scanners should be enabled to ensure that any acute stroke scan gets automatically routed to the correct destination host. Images are viewed by the acute stroke provider and often the neurointerventionalist such as a neurosurgeon, neurologist, or radiologist to make a thrombectomy determination. AI companies often have built-in alerts for LVO detection and other critical imaging findings noted the AI algorithm.

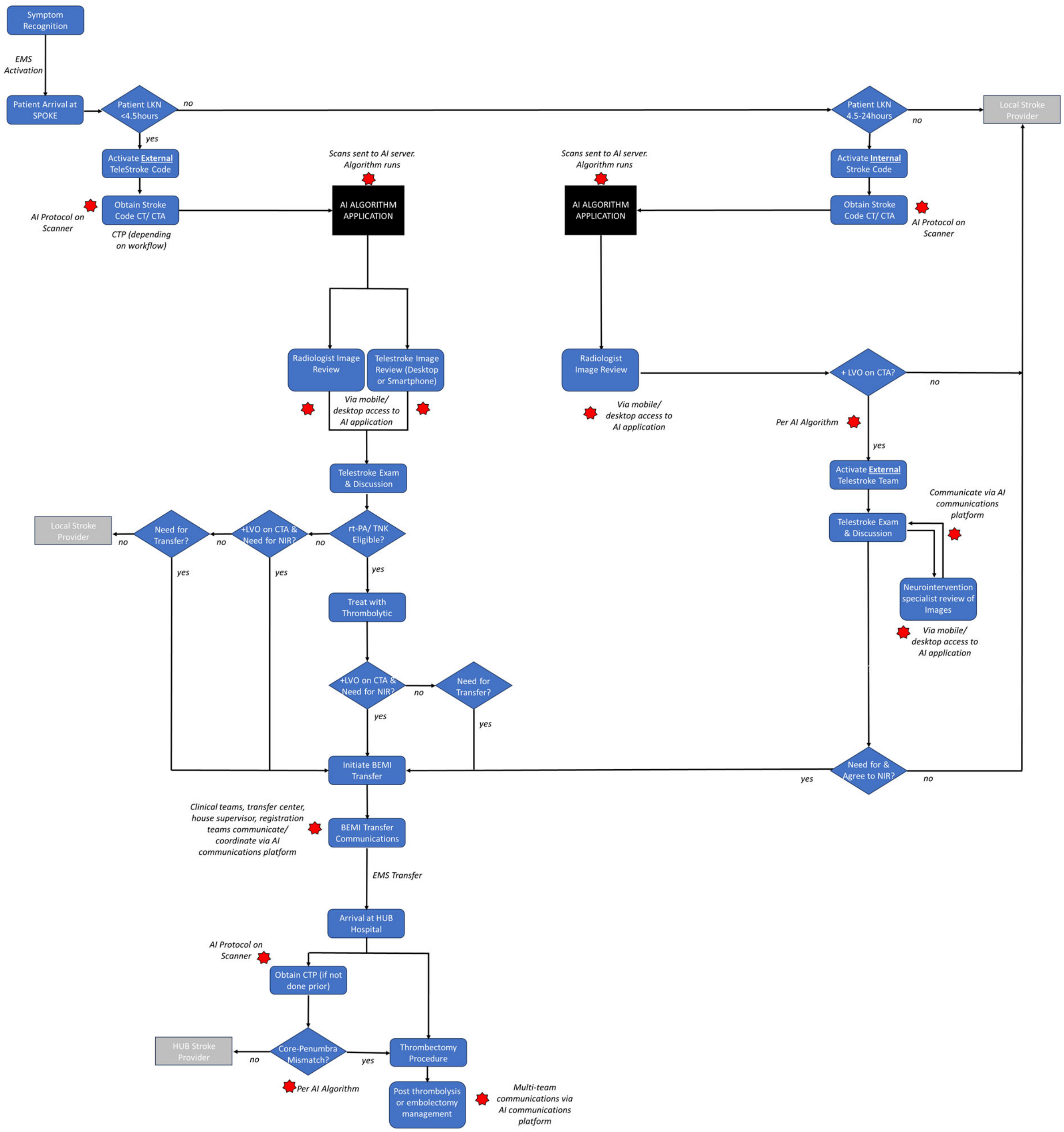

Figure 1: Flowchart of telestroke steps (*AI application areas marked with stars*).
The flowchart shows the progression of a stroke patient throughout the telestroke evaluation and transfer process. Numerous application areas where AI can be integral to care are marked with red stars.

Prior to implementation, spoke sites should be encouraged to ensure correct CT or MRI scanning protocol configuration. As is done for ensuring optimal scanning parameters for standard non-contrast CT and CTA in all stroke codes, the AI algorithms often require specific scanning protocols on specific scanner makes and models. Results may vary based on scanners and protocols used.[25-27] Each vendor has detailed understanding of different scanners and modifications to scanning protocols that should be configured. It is critical to ensure correct protocols are in place, balancing clinical need, patient safety, and AI algorithm function. Similarly, data security and privacy concerns should be addressed with detailed security reviews if patient related information will be transmitted outside of the spoke hospital's firewall-controlled security network. Finally, there may be need for hundreds of providers to have access to these images. This depends on whether only the core telestroke team is utilizing the AI tool, or if multiple specialties and services are going to interface (e.g. stroke neurology, neurosurgery, neuroradiology, imaging and angio-suite teams, transfer center, registration, neurocritical care, etc.). If so, time should be allocated to configure the desktop or smartphone devices for those users who would be accessing these tools. AI vendors can provide further guidance on configuration. Technology support for users is critical for successful AI platform use. AI vendors often have support lines for contact, or even buttons built into the application to notify technology support about an issue. Determining the tech support model at the time of contracting should not be overlooked.

Operational Workflow

Telestroke networks have had to adapt to evaluating stroke code patients even out to 24 hours from symptom onset. Though this additional coverage need has strained telestroke networks, methods have been put in place to evaluate this subset of patients (within the 4.5 to 24 hour window) simply based on neuroimaging that can be done at the spoke center. Telestroke programs that primarily evaluate for thrombolytic therapy need, can use standard noncontrast head CTs to rule out presence of ICH. Those telestroke teams that cover the expanded thrombectomy window often do so using some form of extended stroke radiographic assessment (ESRA) Window. This technique allows for designation of two different stroke code pathways at the spoke hospital (Figure 1). In the "external" stroke code pathway for patients within the 0-4.5 hour window, the external telestroke team is activated, the patient obtains a stat CT/ CTA, and the patient is assessed for thrombolytic therapy and thrombectomy. In the "internal" stroke code pathway for patients in the 4.5-24 hour window, only local spoke resources are activated to quickly obtain a stroke code CT and CTA. In this pathway, the "external" telestroke team is activated only if the CTA shows a +LVO. The telestroke team then evaluates the patient for potential step-up-in care for possible thrombectomy or other considerations."

Once the telestroke team is notified, the patient can be evaluated and the CT/CTA images can be viewed on hub providers' mobile smart-phone devices or desktop computers. It is important to have deep familiarity with the tools embedded in whichever AI tool the team uses. Knowing the appropriate tabs to select to view the patient's image, and which settings to enable or disable (such as CTA completion alerts, CTP completion alerts, or LVO detection alerts) can streamline the process for the telestroke specialist. If an LVO is noted on the CTA imaging, endovascular specialists (neurosurgeons, neuroradiologists, or neurologists with endovascular training) on the hub team can also utilize mobile imaging access to make the final determination regarding need for transfer based on the reported AI algorithms. Some programs may employ the use of CTP at the spoke center, while others reserve this step for hub-side arrival to avoid multiple additional exposures to radiation and contrast boluses for both the CTA and CTP. Our institution performs the CTP upon arrival to the hub site, as hours may have elapsed between original CTA and final arrival at the hub hospital. Although we have a strong emphasis on door-in-door-out (DIDO) and door-out-door-in (DODI) times, and our own Brain Emergency Management Initiative (BEMI) rapid transfer process has been shown to improve transfer time metrics,[28] even in the best-case scenario, an hour or two would have elapses between initial CTA and the time the patient is present at the angio-suite.

Upon transfer to the center with endovascular expertise, CTP can be immediately done just prior to being taken to the angio-suite. The hub-side stroke clinician team, made up of various members often including stroke neurologists and nurse practitioners with advanced training in stroke, should be waiting for the patient to arrive and continue the evaluation and treatment process. The AI enhanced CTP image will often determine whether a mismatch is present and is likely the final decision-making step prior to embolectomy. AI platforms automatically calculate CTP mismatch by using their AI algorithm to optimally measure both the arterial flow into the tissue and the venous outflow out. This allows curve generation and subsequent color mapping of areas determined as likely salvageable penumbra and infarcted core tissue. These inflow and outflow curves, and their resultant color maps, are generated by the AI algorithm automatically. Some AI platforms allow the provider a choice to re-calculate these curves if the provider feels alternate curves are more appropriate. Upon completion of the thrombectomy, usual critical care pathways are continued. There are numerous steps along the telestroke care pathway, where AI elements are applied, and are becoming critical (Figure 1).

Implementation Workflow

Choosing an AI vendor is not a simple process as numerous variables need to be considered. These variables include use case, platform features, algorithm reliability and accuracy, useability, education/training needs, price, HIPAA security, and vendor support/availability just to name a few. Programs that choose an AI vendor without first doing their own detailed needs assessment, may fail to optimally meet their program requirements. An assessment of resource availability is just as important. Spoke sites without the capability to perform hyperacute MRIs for instance, would not benefit from an AI partner focused on MRI-based algorithms. This is a recapitulation of the telestroke network fundamentals lessons learned for the use of telestroke in the early 2000s.[29] Equipment purchased without built-out infrastructure, a clear strategic plan, and an assessment of end-user needs may result in equipment that is not used or used appropriately. Telestroke programs who bought telestroke equipment first, often ended up with telemedicine carts, robots, and peripherals such as stethoscopes and otoscopes that simply didn't meet the need in the acute telestroke use case. Our mantra has always been to "buy the equipment last." A critical analysis of the development, validation, reliability, efficacy, and clinical outcomes should also be performed. Many vendors have ample literature to justify the use of their product, but the importance of assessing the validation data and published research supporting the use cannot be overstated.[16,30-33]

Table 1: Example Telestroke AI Implementation Checklist

☐	Clinical Partnership	Develop telestroke partnership (e.g. hub & spoke model). Development of contracted care pathway expectations should detail hours of coverage for patients presenting with stroke-like symptoms within X hours from last known normal. This should facilitate assessment of patient who may benefit from thrombectomy based on AI algorithms.
☐	AI Needs Assessment	Do a needs assessment focused on hub needs, spoke resource availability, and patient evaluation goals. Determine which AI elements would be required and in what time window.
☐	AI Vendor Assessment	Assess different AI vendors for available tools (LVO detection, mismatch algorithm, automatic ASPECTS, ICH detection, aneurysm assessment, collateral scoring, 3D reconstruction, rotation, ability to re-calculate perfusion curves, radiology worklist integration, etc.) and assess price points.
☐	Security/PHI Review	Hub and spoke should perform security review to ensure vendor processes have been cleared for handling of patient health information in a secure fashion. Determinations as to where AI server will reside (within hospital firewall or outside of firewall) should be included.
☐	Contracting and Support	Develop contract with AI vendor for algorithms needed. Often, this decision is required from a higher perspective if it includes more services than just telestroke (e.g. neurosurgery, pulmonary, structural heart, cardiac electrophysiology, etc.). Include discussions of technology support and maintenance.
☐	Clinical & Operational Team Inventory (Hub)	Relevant clinical teams should be determined. Point-persons from each of these disciplines should be convened to discuss and develop agreed upon workflow and "rules of the road."
☐	Clinical & Operational Team Inventory (Spoke)	Relevant clinical teams should be determined. Point-persons from each of these disciplines should be convened to discuss and develop agreed upon workflow and "rules of the road" forming the basis for "standard telestroke work."
☐	PACS/IS Configuration	Configure CT and MRI scanners to perform appropriate stroke protocol using AI vendor provided scanning protocols. Develop VPN-like solutions to transmit images to the AI server for application of the AI algorithm. Enable transmission from server to provider- accessible computer or smartphone (based on hub-side specific workflow needs).

☐	Workflow Implementation Meetings	Frequent meetings (e.g. weekly) can allow the clinical/ operations workflow team to address outstanding concerns and solve implementation/training issues. Project management resources, and regular cadence of reporting interval results should be encouraged. The goal should be highly reliable pathways that follow "standard telestroke work."
☐	Implement ESRA Pathway	Establish relevant hub and spoke stroke code pathways that can take advantage of AI algorithms for stroke assessments. These may include "internal" stroke code pathways which only notify the spoke team to obtain stat head CT/CTA, and "external" stroke code pathways that immediately incorporate the telestroke team activations.
☐	Train Hub Providers	Train hub providers on AI components of telestroke workflow. Usually this only necessitates minimal changes to the workflow, with augmentation of LVO and mismatch detection by incorporating AI tools into the evaluation pathway.
☐	Configure Devices	Although limited effort will be required, a basic training overview/document should be developed so providers have familiarity with the algorithm and smartphone application (button-ology).
☐	Optimize Transfer Processes	Ensure rapid transfer process are put in place (e.g. BEMI transfer protocol) to account for a possible increase in need for patient transfer for assessment of potential thrombectomy.
☐	Monitor Performance	Continually assess performance to improve workflow, and routinely assess for desired outcome (e.g. degree that the algorithm accurately detects, under-detects, or over-detects an LVO). Multi-stakeholder teams should meet regularly to assess the workflow and modify if/when needed.
☐	Quality Reporting & Governance	Overall governance strategies should be in place to ensure appropriate use of any AI tools (e.g. development of an AI steering committee, incorporation of this pathway within a quality reporting structure).

Table 1 illustrates an example of a telestroke AI implementation checklist. Implementing AI solutions within a telestroke program assumes a general telestroke infrastructure is already in place. These additional elements, all AI related, should be considered when implementing an AI solution into a telestroke network.

The needs assessment absolutely includes an inventory of the clinical teams requiring interface with the AI tool, and at what step in the process. An AI tool focused on improving radiologists' efficiency in interpreting scans would be expected to be integrated into few other clinicians' workflows, while one designed specifically to help determine critical findings of LVO or CTP mismatch would be expected to be used by a great number of team members at various AI touchpoints in the chain of survival (Figure 1). These providers, in the case of extended window LVO and mismatch assessment, include stroke practitioners, neurosurgeons, neuroradiologists, interventional radiology teams, CT and angio-suite technicians, registration, transfer center, and neurocritical care team members. Point-persons from each of these disciplines should be convened to discuss and develop agreed upon workflows. These workflows should form the basis of Lean Methodology "standard work" for telestroke as has been shown in other multidisciplinary stroke settings.[34] Including both hub and spoke medical directors is important to understand key pain-points and clinical needs of both sides of the partnership. Having regular implementation meetings with the AI vendor to overcome technical and clinical obstacles is the next step in the implementation workflow. Although many of these AI tools are invisible to the end user (such as the algorithm itself running in the background of image processing) some require training for the hub team members. Training the hub and spoke providers in the workflow is just as important. A spoke team sending a patient for CTP or MRI to assess perfusion mismatch, when transfer to the hub institution may take 2 hours, would likely not be the ideal workflow. Reviewing the expected workflow with the providers to streamline care and transfer should be performed. Ensuring spoke CT technologists understand the urgency with which to transmit these AI augmented CTA images to the hub team is also important in the training process.

Performance Monitoring

Upon choosing an AI platform for telestroke, important guardrails should be ensured such as continued assessment of performance, improvement of workflow, and routinely assessing for desired outcome. This includes assessing the degree to which the algorithm accurately detects, under-detects, or over-detects an LVO. Multi-stakeholder teams should meet regularly to assess the workflow and modify it when needed. Overall governance strategies should be in place to ensure appropriate use of any AI tools such as the development of an AI steering committee, or the incorporation of this pathway within a quality reporting structure.

Final Checklist

As a practical guide to implementing AI in telestroke networks, providers and administrators may find it helpful to refer to an overview checklist to help guide these implementations. In our center, we utilized a checklist (Table 1) as the core feature in developing the standard processes of both our implementation and ongoing process, finding that it helped our implementation to go smoothly. This checklist should serve simply as an overall starting point for a more granular implementation plan, as each item would of course necessitate sub-checklists for a successful implementation.

Conclusion

Acute telestroke care has always been a fast-paced process filled with parallel processing (e.g. clinical evaluation over the camera, while simultaneously assessing CT scans for presence or absence of thrombolytic contraindications, all while assessing for the need for/operational ability to transfer patients for potential embolectomy). With the adoption of AI for stroke, the tools for finding and treating more patients are now more available. Determining how and when to implement them into the chain of telestroke survival is the next goal of care in stroke. In this manuscript, we posited the use of AI in telestroke workflows with emphasis on different platforms, technology and infrastructure requirements, operational workflow considerations, and use within transfer processes. Implementing AI into telestroke processes has been a game-changing approach to stroke care. The rapidly expanding AI toolbox is opening, and stroke clinicians need to be aware of how to assess and use these tools properly.

Author Affiliations

Drs. Brett and Dawn Meyer, Bavarsad, Agrawal, Modir, and Hemmen are telestroke and stroke program faculty at the University of California, San Diego (UCSD); San Diego, CA USA.

Ms. Mortin and Hailey are advanced practice providers on the UCSD stroke team, San Diego, CA USA.

Dr. Wood is stroke program faculty at University of California, Davis, Davis, CA USA.

Corresponding Author

Brett C. Meyer, MD
Professor & Co-Director, UCSD Stroke Center
Clinical Director of UCSD Enterprise Telehealth
bcmeyer@health.ucsd.edu

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