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STROKE (JF MESCHIA, SECTION EDITOR)

Telestroke

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Abstract
Purpose of Review This study aims to describe the current state of telestroke clinical applications and policies, in addition to key technical and operational aspects of the telemedicine practice.
Recent Findings Delivery of telestroke services for neurovascular care expanded from the intravenous alteplase decision and administration in acute emergency department settings to a continuum of services in mobile and inpatient stroke units, intensive care units, virtual stroke clinics, rehabilitation, and clinical research. Telestroke cost-effectiveness is well established from multiple perspectives. Stroke centers, certification agencies, and national registries have made essential recommendations regarding telestroke quality measures monitoring and reporting.
Summary Telestroke continues to bring neurovascular expertise to resource-restricted areas with advanced virtual communication techniques, optimizing stroke care. Future research should aim at broadening telestroke technology applications, while improving quality and reducing the delivery-associated cost and resources. Comprehensive multidisciplinary virtual telestroke centers that cover all aspects of stroke management might become available in the future.

This article is part of the Topical Collection on *Stroke*

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Introduction

Telemedicine is defined as the use of medical information exchanged from one site to another using electronic communications in an effort to improve health status [1••] and to deliver medical and educational services [2•] in emergent and ambulatory care settings. Inpatient and outpatient teleneurology are emerging subspecialties in neurology [3], developed to improve access to neurological care in underserved areas.

Increasing global morbidity and mortality caused by stroke [4] is in part caused by insufficient resources and healthcare providers in rural and low-income regions. Telestroke is the most rapidly evolving and best-recognized application of teleneurology in the USA, with proven benefits to provide prompt and expert evaluation and management, thus overcoming geographical and time-based barriers in access to appropriate neurovascular services [5, 6].

Clinical Applications

The 2009 guidelines for acute stroke management [7] underscored the importance of telestroke in the immediate clinical and radiographic assessment of stroke severity, quick diagnostic decisions and establishing of intravenous alteplase candidacy. Similarly, telestroke can be used to support specialized care in inpatient stroke units. More recently, in the era of endovascular therapy, telestroke is applied to triaging in emergency departments and in pre-hospital settings, in ambulances, and mobile stroke units.

Telestroke services have demonstrated value in decision-making for patient suitability for intravenous alteplase [8], diagnostic accuracy [9], interpretation of brain scans [10], improving process times [11], transfers to stroke centers for routine post-alteplase intensive care or for hemorrhagic stroke intensive care management, and transfers to a higher level of neurosurgical care for patients with intracranial hemorrhage requiring hematoma evacuation or with malignant cerebral infarction in need of decompressive hemicraniectomy [12]. These virtual services have exhibited similar quality with in-person assessments [13].

1. Telestroke for Hyperacute Stroke Care in the Emergency Department (ED)

Telestroke physicians' roles in evaluating the patients presenting to remote EDs with acute stroke syndromes are to determine a correct diagnosis, to promptly decide alteplase therapy, and guide transfers to appropriate centers for continuation of care.

Multiple studies have evaluated the benefits, feasibility, and safety of telestroke services to facilitate acute stroke therapies in EDs lacking local continuous vascular neurology coverage, when the time-to-intravenous alteplase administration is critical for improving stroke outcomes [11, 14–16]. The American Heart Association/American Stroke Association recommends the use of high-quality video teleconference to provide medical opinion for the use of intravenous alteplase in patients with suspected acute ischemic stroke when onsite stroke expertise is not immediately available (class I recommendation, level of evidence B) [17]. After telestroke implementation, standard of care acute stroke therapies with intravenous alteplase became more broadly available and showed increased rates [6]. Functional outcomes and mortality are similar between specialized stroke centers and telestroke-served hospitals [18].

Telestroke evaluations are preferably performed using a two-way audio-visual consultation with additional laboratory and teleradiology review. Participating sites' personnel should be trained in National Institute of Health Stroke Scale (NIHSS) performance to help with parts of the examinations (visual fields and somatosensation). Remote NIHSS evaluations are shown to be similar to onsite examinations for acute and subacute stroke patients [19], including via smart phones [20].

The phone-only consultations should be used as back-up if technical difficulties are encountered. The National Institutes of Health–funded Stroke Team Remote Evaluation using a Digital Observation Camera (STRokE DOC) trial was terminated early when telephone-only medical decision making was determined to be inferior to the telestroke arm overall, although the rates of post-stroke intracerebral hemorrhages were similar [8].

Teleradiology studies showed that emergency interpretation of electronically transferred CT scans by the telestroke physicians is reliable [21, 22]. Fair interrater agreement (balanced kappa score of 0.61–0.63) between stroke neurologists and expert neuroradiologists in ASPECTS (Alberta Stroke Program Early CT Score [23]) interpretation was reported, without significant effects on outcomes [21]. Imaging workflow often includes CT angiography of head and neck, if it can be completed rapidly without unnecessary increase in door-to-groin puncture time or delaying transfers for endovascular therapy.

Endovascular reperfusion therapy is currently recognized as standard of care after multicenter clinical trials demonstrated its value in addition to intravenous alteplase, in a subset of patients with large vessel occlusions [24]. Telestroke physicians play an important role in screening, triaging, and identifying patients that are potential candidates for endovascular therapy [25]. Studies reported improved triage [26], faster intervention times (door-to-groin puncture time, 47 vs. 69 min, $p = 0.04$) [27], and better functional outcomes (mRS equal or less than 2 at 3 months, 36.8% vs. 15.8%, $p = 0.04$) in patients evaluated via telestroke prior to endovascular procedures [27]. Telestroke networks may assist in delivery of endovascular treatment to candidate ischemic stroke patients transferred from remote hospitals that is similar to patients admitted directly to tertiary hospitals [28••].

In addition to the endovascular therapy capabilities, if the originating sites lack post-intravenous alteplase care or vascular neurosurgical capabilities in selected clinical scenarios, patients should be transferred to the closest stroke center with these capabilities. A priori plans for patient transfers should be established that take into consideration the capabilities of the receiving center for intervention and monitoring and absolute distance and time of therapy administration [13], so that all aspects of neurovascular case are covered in a timely and organized fashion.

For patients with hemorrhagic strokes (intracerebral hemorrhage and subarachnoid hemorrhage) that present to rural hospitals or hospitals lacking neurosurgical expertise, telestroke specialists help select patients who need advanced neurological and/or neurosurgical care [29]. Despite recognized high mortality rates, early and aggressive administration of medical, surgical, and endovascular therapies are essential.

Expert telestroke consultations are valued for subjects that are not candidates for acute stroke therapies or have a stroke-mimic syndrome [15, 30]. About one fifth of acute telestroke consultations are reported to be stroke mimics [31], and nearly one fifth of them are treated with intravenous alteplase [30]. Using several tools that were developed for bedside discrimination [32] in adults and children, the telestroke physicians aim to minimize stroke mimics treatment with intravenous alteplase [33]. Their diagnostic impression, management, and disposition should be discussed with the originating site emergency physician in order to assure good quality neurological care and prevent unnecessary hospital admissions when indicated.

A consultation note generated by the consulting telestroke physician should be made available to the originating site and be included in the medical record. Discharge summary including a definitive diagnosis should be sent to the telestroke physician. The complete documentation is used for monitoring important quality measures.

2. Telestroke Across Continuum of Stroke Care

In pre-hospital stroke care, telestroke applications are variable and parallel those in the EDs, with inherent new challenges. An unassisted telestroke examination scale was evaluated with healthy volunteers mimicking stroke syndromes during ambulance transportation, and sufficient stability was demonstrated in a moving ambulance using 4G connectivity [34]. Stroke expert evaluations in mobile stroke units reduced the time to alteplase delivery relative to regular ambulances transporting patients to closest EDs [35, 36].

In mobile stroke units, neurologic examination and CT imaging interpretation via telestroke opens the opportunity for fast clinical decision-making for intravenous alteplase administration in the field, which is critical considering that reduced assessment and treatment times in pre-hospital setting are associated with better outcomes [37]. Furthermore, 98% satisfactory connectivity and 88% agreement on the alteplase decision was demonstrated in a study of simultaneous and independent assessment by a stroke specialist in the mobile stroke unit and a remote telestroke physician [38]. Decisions for subsequent transfers to either the closest center with neurocritical care monitoring or the closest center with endovascular capabilities are made after alteplase administration in the mobile stroke unit.

Teleneuro-intensive care units become important beyond the hyperacute phase of stroke. Teleneurocritical care is valuable for prevention, diagnosis, and the timely management of cerebrovascular conditions, induced secondary neurologic injuries [39], with demonstrated reliability and improved outcomes [40].

The concept of electronic stroke unit [2] referring to remote teleneurovascular services for patients admitted to stroke units without continuous neurology or stroke coverage has somewhat limited applicability currently, compared to the hyperacute electronic stroke care settings.

The rehabilitation field of telestroke was studied in home and ambulatory settings for serial neurologic assessments and timely adjustments of therapies. Moderate evidence showed that telerehabilitation approaches are comparable to conventional rehabilitation in improving activities of daily living and motor function for stroke survivors [41, 42]. Potential obstacles are patients' and caregivers' lack of technology understanding and variability in resources between different virtual telerehabilitation networks.

Stroke secondary prevention and monitoring via telestroke services (virtual neurovascular clinic) is another telestroke application, which is growing in rural areas and long-term care units, for patients with reduced mobility and transportation options [2]. The virtual applications of transcranial Doppler ultrasound and carotid duplex ultrasound via teleneurosonology showed technical feasibility in a proof-of-concept study [43]; its routine applicability in inpatient or outpatient settings warrants further investigation.

3. Telestroke in Clinical Stroke Research

Telestroke encounters may assist to identify patients who are eligible for trials of therapies for ischemic and hemorrhagic stroke, neuroprotective agents, or innovative diagnostic tests. The patients' enrollment can happen at the originating sites, in an expedited fashion after transfer to stroke centers [44], in the mobile stroke units or virtual stroke clinics [45]. The investigators should be familiar with the eligibility criteria and research protocols and, when appropriate, offer the patient the opportunity to participate in clinical trials and obtain informed consent. The projects should comply with approved research policies.

4. Telestroke in Education

Telementoring or telestroke applications in neurology trainees' medical education using virtual supervision is emerging in numerous training programs [3]. In-person faculty supervision was preferred over robotic telepresence and telephone-only consultations in a study conducted at the Mayo Clinic [46]. Various intensities and training methodologies are applicable for medical students, residents, and neurovascular fellows. Different models of formal incorporation of telestroke training during neurovascular fellowship were proposed [47], without any specific recommendations existing currently to guide training programs accreditation agencies. Similarly, simulation training for emergency teams [48] and nursing staff [49] demonstrated to be successful approaches for virtual stroke management.

Technical Considerations

Telestroke networks are designed as a combination of primary, secondary, and tertiary care settings [1] working together to provide comprehensive stroke care. Currently, there are two mainly used telestroke models: distributed and hub-and-spoke. They include distant sites where the telestroke physician is located and originating sites where the patients in need for stroke evaluation are located. The services at all sites for acute stroke syndromes need to be available 365 days a year, 24 h a day, and 7 days a week.

In the hub-and-spoke model, a comprehensive stroke center or academic medical center provides expert consultative services at remote sites to the patients at spoke sites. Sub-hubs can also be integrated in this model, mainly consisting of small community hospitals that can serve some spokes and are linked to the main hub [50]. The telestroke physicians are credentialed at the hub and all spoke sites. Their services consist of immediate evaluation of patients and clinical decision for acute therapies and subsequent management in the most appropriate setting, including transfers decisions and involvement in clinical trials, if applicable.

In the distributive model, an independent corporation or affiliated network of telestroke physicians provides services at various originating sites.

Some networks include virtual telestroke units, allowing patients to remain in the original hospital with access to higher quality stroke care by providing additional resources like therapists and ongoing telestroke consultations [51].

Decentralized telestroke thrombolysis service was shown to achieve similar treatment rates and time delays for a rural population as a centralized system can achieve for an urban population [16].

Irrespective of the model, well-delineated workflow protocols and agreements for inter-facility transfers for higher level of care need to be established and available to all team members at any time. Training and maintenance of continuous education should be provided to all telestroke providers and consulting services (physicians, nurses, and ancillary staff) at both the distant and originating sites. Clinical and technical roles and responsibilities need to be acknowledged.

Telestroke Quality Measures

An external organization should certify the telestroke network, based on review of performance, processes, and outcomes metrics. Measures of quality performance should be collected in a standardized fashion and shared across the network, according to an agreement between telestroke sites and either a coordinating stroke center or distributed partner [13]. Every telestroke network hospital should collect stroke quality measures [52].

Current American Heart Association guidelines make suggestions for measuring different telestroke measures [13], such as process and performance, outcomes, patient and provider satisfaction, and technology quality (Fig. 1). Their reporting is also recommended for stroke center certification and national registries, such as Get With The Guidelines. Administrative, technical, and clinical quality indicators should be systematically and regularly reviewed by telestroke leadership in order to assure quality and constant improvement.

Operational Considerations

Policies and procedures for telestroke networks operation and administration must be developed and strictly followed to assure good quality clinical care and organizational success. Key stakeholders include hub and distant sites physician directors, program manager, ED stroke champions, EMS personnel, information technology administrators, laboratory and radiology personnel, human resources, and legal and finance providers. Personalized algorithms and guidelines for each setting of the telestroke consultation (ED, mobile stroke unit, intensive care unit, medical-surgical floor, outpatient) should be created and be readily available to the involved personnel. Continuous oversight, timely feedback, and staff development are indicated to assure telestroke program maintained competency. Patient records' maintenance and retrieval, and their privacy and confidentiality should follow HIPAA and individual state laws. American Telestroke Association published technical requirements for operation [1].

Physicians licensing and credentialing [53], infrastructure development, staffing, training, partnership development, fragmentation of care, limited coordination [5], and reduced internet access for people living in rural areas are reported as obstacles to telestroke implementations. Different states have adopted a variety of policies to facilitate the adoption of telestroke services and overcome licensing, liability, and reimbursement [54].

Cost-Effectiveness

Analysis of several telestroke networks demonstrated an increase in the number of patients discharged home independently and reduced costs for the network hospitals [55], with the highest cost-effectiveness revealed in most severe strokes cases [56]. Societal perspective similarly indicated cost utility of the hub-and-spoke networks [57]. In resource-limited developing countries, affordable smart-phone based technology was pioneered and was associated with improved outcomes [58]. Mobile telestroke assessment was also shown to be feasible using low-cost components and commercially available wireless connectivity in rural settings [59]. Likewise, teleneurological intensive care units are described as safe and cost-saving strategies that improve the timely response to neurologic emergencies and decrease hospital lengths of

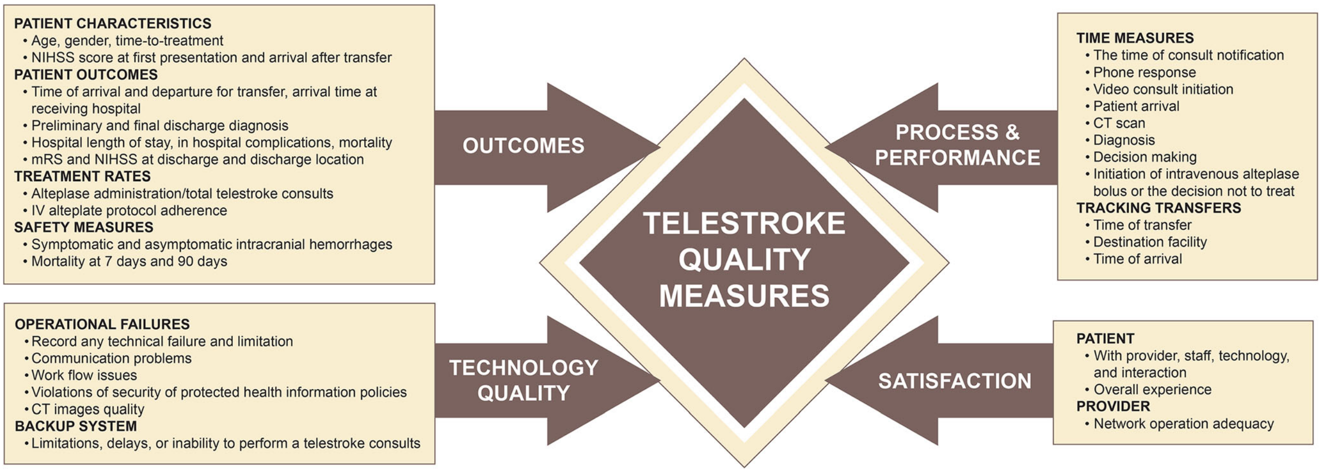

Fig. 1 Current telestroke measures as guided by the American Heart Association/American Stroke Association

stay [40]. Whereas pre-hospital stroke care can be cost-effective [60], the mobile stroke unit associated budget remains to be determined. Teleneurology for patients in ambulances (in-transit telestroke) was shown to be a scalable and affordable alternative to mobile stroke units, with similar efficacy in diagnosis and treatment [61].

Various financial models are tailored to the objectives of each telestroke program and are dynamically reevaluated, given reimbursements agreements could represent barriers of the telestroke networks fulfillment [5].

Prospective Comprehensive Virtual Stroke Centers

Most current telestroke providers are vascular neurologists, general neurologists, and neurocritical care specialists. Virtual assessments and management of more complex neurovascular emergencies are likely to be associated with improved outcomes when patients have prompt, seamless, and integrated neuroradiological, neurocritical care and neurosurgical expertise available, in addition to the vascular neurology opinion and coordination of care [62].

From the introduction of portable CT scanners in rural EDs [63] to multimodal CT imaging [64] and CT angiography in mobile stroke units that improves patient selection, quality control of teleneuroimaging interpretation is recommended [65]. Therefore, the addition of a teleneuroradiologist to the virtual stroke team is preferred, especially for interpretation of more advanced neuroimaging techniques for complex neurovascular cases. Compound cerebrovascular conditions require emergent neurosurgical and/or neurocritical care management [40]. Early rehabilitation post-stroke is critical [66]. Telerehabilitation starting with early dysphagia assessment and ending with virtual visits in long-term care facilities for therapy adjustments are resourceful [67, 68].

The recommendations for comprehensive stroke centers delivery of specialized stroke care are their including of healthcare providers with expertise in neurosurgery and vascular neurology, access to advanced neuroimaging capabilities, surgical and endovascular techniques, intensive care unit, and a stroke registry [69]. Correspondingly, virtual comprehensive stroke networks should be multidisciplinary and follow key accreditation guidelines in an organized, systematic, and efficient manner. National registries that collect and monitor telestroke outcome measures should assure standardization of best telestroke practices.

Conclusions

With evolving stroke care, telestroke applications have expanded too. Virtual neurovascular assessments in underserved areas overpowered the limited access to well-timed stroke care expertise and currently represent standard practice nationally and internationally.

A comprehensive multidisciplinary telestroke team focused on broader neurovascular care should be formed by a tele vascular neurologist, tele neuroradiologist, tele neurocritical care specialist, and tele neurosurgeon, supplemented by telestroke midlevel and nursing personnel in the acute phase; tele therapists should be added in the subacute phase when transitioning to rehabilitation takes place. Prospective research should analyze the benefits of comprehensive versus primary virtual stroke centers, from the hospital and societal perspectives, their associated costs, resources, optimal implementation, and functional strategies.

Key Clinical Points

- Telestroke was originally designed to provide decision-making services including assessment, diagnosis, management, and disposition to patients with acute stroke-

like presentations in the emergency department on a 365/24/7 basis.
- Standard of care therapies for acute stroke are facilitated by telestroke, with increasing intravenous thrombolysis rates and rapid endovascular therapy candidacy determination.
- Cost-effective telestroke applications have broadened to acute stroke care in inpatient settings and pre-hospital mobile stroke units, subacute stroke care, rehabilitation, virtual stroke clinic with secondary prevention goals, and clinical research.
- The individualized scope of each telestroke program and its business plan should be determined and agreed upon by all parties involved.
- Continuous and multifaceted performance review, quality assurance, and re-assurance processes are mandatory measures.

Compliance with Ethical Standards

Conflict of Interest O.M.D. and B.M.D. declare that they have no conflict of interest.

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

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