Review Article

TeleStroke for acute stroke: progress and future perspective as a focused stroke care solution

Abstract

Stroke remains one of the leading causes of death and disability worldwide. In time-sensitive clinical conditions such as acute ischemic stroke, immediate treatment with the use of intravenous tissue plasminogen activator and mechanical thrombectomy, is essential for clinical outcomes improved in patients with acute ischemic stroke.

However, geography and distance contribute to the disparity in acute stroke care, as most neurological centers are usually at large urban medical centers and academic medical centers.

Telestroke addresses inequities in access to vascular neurologists, alleviating delays in urgent diagnosis and treatment for acute stroke patients, particularly in rural or low-resource settings. Telestroke leverages cutting-edge technologies that enable high-resolution, and two-way video conferencing to help remote and underserved regions, which often lack on-site stroke neurologists, provide high-quality stroke care. A telestroke program can be set up using a hub-and-spoke model or as a distribution network. The core of the hub is typically a comprehensive tertiary care center staffed with acute stroke specialists, providing telestroke services to partner sites such as small hospitals, mobile stroke units, and emergency departments.

Artificial intelligence and machine learning can revolutionize remote stroke care, as these systems can facilitate faster and more accurate diagnoses and treatment planning. From this outline, it has been shown that shorter treatment times, higher thrombolysis rates, and improved functional outcomes compared to conventional stroke systems of care. Despite the proven effectiveness of telestroke for rapid expert management and decision making of hyperacute stroke, its adoption around the world and in other nations remains variable. Further studies evaluating the types of patient transport models and types of telemedicine will be needed to ensure proper assessment of the implementation, especially in less developed or low-income regions. As remarked above, this innovative healthcare solution aims to bridge the gap in geographic and socioeconomic stroke care. This article explores various facets of telestroke technology, shedding light on their role in improving stroke care.

Keywords: acute stroke, stroke care, prehospital Stroke Care, telestroke, telemedicine, teleconference, mobile stroke unit, teleconference, artificial intelligence, 5G technology

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Introduction

Stroke is recognized as the second most common cause of death worldwide, accounting for 11.8% of all deaths, more fatalities is ischemic heart disease, which leads with 14.8%.[1] Acute strokes are divided into ischemic and hemorrhagic types with some overlapping in risk factors and clinical presentations and the first distinction is to separate ischemic from hemorrhagic stroke. Stroke ranks as the second leading cause of death and is a major contributor to disability worldwide.[2]

The American Heart Association reported that in 2022, the United States experienced roughly 765,000 cases of stroke.[3] Furthermore, stroke presents a considerable public health challenge within the countries, especially in low- and middle-income countries.[4] The global incidence of strokes is increasing significantly due to the aging population; consequently, World Stroke Organization (WSO) is leading a global call to action to increase access to reperfusion services for acute stroke.[5]

Acute ischemic stroke (AIS), the most common type, occurs when blood flow to a part of the brain is blocked, leading to cerebral infarction. The main causes of AIS are cerebral embolism and atherosclerotic-thrombotic disease of extra cerebral or cerebral vessels. In case of an AIS, top priority of treatment is restoring blood flow as quickly as possible to the afflicted region of the brain.

In the final analysis, AIS is a medical emergency access to timely, evidence-based care is critical to reduce neurological damage and mortality. The severity of the stroke deficit may reflect some combination of infarction and ischemic, but not yet infarcted, tissue.

It should be emphasized that ischemic but not yet infarcted portion is called the penumbra and current therapy of acute stroke is focused on determining the extent of the size of the region reversible ischemia and improving it by re-establishing blood flow. This means in the zone of penumbra represents salvageable brain tissue; cerebral blood flow (CBF) is reduced typically between 10–20 mL/100g/min, but it has not yet arrived at significance level to cause neuronal cell death. With time, there have been remarkable advancements in the early diagnosis and treatment of ischemic stroke.[6]

In the present day, intravenous thrombolysis (IVT) and mechanical (also called endovascular) thrombectomy (EVT) represent the standard of care in acute stroke patients with large vessel occlusion (LVO), and they are highly time-sensitive treatments, with an increased proportion of poor outcomes associated with delayed delivery, which is discussed further on. Their use is strongly recommended in current guidelines.[7] It is also worth noting that prior to EVT, intravenous thrombolysis (IVT) was the mainstay of acute ischemic stroke treatment.

For the convenience of exposition, IVT and EVT aim to save the ischemic penumbra reversibly damaged brain tissue surrounding the infarct core.[8] However, it is noteworthy that primary stroke centers (PSCs), which were established to facilitate access to acute stroke care and IVT in densely populated regions, are not equipped to provide EVT.[9]

The acute treatment process involves quickly assessing a patient's eligibility for intravenous or intra-arterial revascularization, with timing based on randomized clinical trials. In more recent years, a meta-analysis of nine randomized controlled trials comparing IVT combined with EVT to EVT alone demonstrated that the combination group achieved superior outcomes in terms of functional independence, as measured by the Modified Rankin Scale (mRS 0–2).[10] Recombinant tissue plasminogen activator (tPA) is the only thrombolytic agent approved by the US FDA, based on the 1996 NINDS Stroke Study.[11] Contemporary management is to use intravenous thrombolysis within 4.5 h of stroke onset and, in some cases, longer.[12]

Wake-up stroke (WUS) is a type of AIS manifesting during sleep with an indeterminate time of symptom onset.

The WAKE-UP study, an MRI-based study, demonstrated the benefits of intravenous thrombolysis with alteplase in stroke patients with undetermined onset who had DWI-FLAIR mismatch findings on MRI.[13] In the WAKE-UP trial randomized patients 18 to 80 years of age with AIS who awoke with stroke or had undetermined time of onset >4.5 hours from last known good and all the patients had an ischemic lesion that was visible on MRI diffusion-weighted imaging but no parenchymal hyperintensity on FLAIR, which suggested that the stroke had taken place about 4.5 hours earlier.

In more recent years, trials have evaluated IV-tPA efficacy between the 4.5 and 9 h window in patients who were not EVT eligible and had a perfusion-to-diffusion mismatch ratio of >1.2.[14] In the case of vascular imaging to carry during or after intravenous thrombolysis treatment shows the occlusion of large vessels (LVO) the patient may be eligible for endovascular thrombectomy with or without previous intravenous thrombolysis. Implementation of EVT for emergent LVO–related AIS treatment increased rapidly after the 2015 publication of multiple randomized controlled trials (RCTs) and an American Heart Association guidelines update.[15] Direct EVT involves using specialized devices to remove or disrupt the blood clot causing the stroke physically.[16] Therefore, EVT is typically conducted only at specialized stroke centers and is not available and is not available in rural hospitals across the country. These special cases require expertise in stroke neurology and neurological interventions that unfortunately are relatively rare, so the increase in global morbidity and mortality caused by stroke is partly due to insufficient resources and health workers in rural and low-income regions.[17]

In cases of LVO and if the patient is seen within 4.5 to 6 hours of stroke onset, EVT may be initiated in stroke patients who meet rigorous clinical and radiological criteria, based on a contrast between perfusion and infarction of the affected region or a contrast, discrepancy between the clinical deficit and the extent of infarction.[18] A notable advance in EVT has been the expansion of the treatment window. The current published literature has demonstrated the efficacy of EVT for up to 24 hours in carefully specific group of patients with ischemic penumbra, offering a longer window for intervention and expanding the number of eligible candidates.[19,20] To recapitulate regarding EVT, the initial trials were conducted in patients up to 6 h after stroke[21] but this time window has been extended to 8 hours[22] and even to 16 to 24 h with appropriate patient selection[23] and possibly beyond.[24] More contemporary also for patients with basilar occlusion and large core hemispheric infarction.[25]

However, despite the clear benefits global use of thrombolysis and thrombectomy remain low. Predominant cause attributed to this is a delay between the development of stroke symptoms and the patient's admission to a hospital which is directly related to patient unawareness, lack of immediate availability of neurological expertise, long distances to tertiary care hospitals, and concerns with the risks of intracranial hemorrhage.[26] There are also significant disparities between rural and urban areas in stroke care, so telestroke programs are designed to bridge this gap by providing neurological expertise in remote areas.

Telestroke Network Models for acute stroke care

Unfortunately, many people live in rural settings that do not have access to hospitals with neurological services.

With the advent of technology, telestroke is emerging as a promising intervention to provide care to stroke victims in rural communities, where acute ischemic stroke treatment is often hampered by limited experience, using a network of audiovisual and computer communication systems, which forms the basis for a collaborative and interprofessional care model centered on acute stroke patients.

Telestroke is designed for allowing patients and doctors who are hundreds of miles apart to communicate instantly and resolve these issues, thus alleviating the difficulties encountered in rural areas in providing access to specialized stroke care. Remote stroke experts in telestroke consultation can interview and examine the patient, review brain imaging, determine candidacy for thrombolysis or thrombectomy, assess the need for transfer, and recommend other treatments, including secondary stroke prevention.

In this way, the experts in stroke neurology and neurointervention are then contacted to discuss stroke management, including reperfusion by IVT and EVT. The American Telemedicine Association disclosed telestroke Guidelines in 2017 detail the resources required to set up telestroke at a site.[27] While, the 2018 guidelines for acute ischemic stroke care of telemedicine for the rapid neurological interpretation of patients with stroke using synchronous audio-video clinical evaluations and diagnostic neuroimaging reviews to make quick identify a patient's condition and determinations of intravenous alteplase candidacy, for guidance over thrombolysis administration and for triaging patients who may be eligible for interfacility transfer for mechanical thrombectomy.[28]

The Commission for Telemedical Stroke Care of the German Stroke Society (Deutsche Schlaganfall-Gesellschaft, DSG) has developed the recommendations on how to organize a teleconsultation service within a telestroke network.[29] Typically, using telestroke network, in originating site, patients receive an initial stroke evaluation, anwhether the emergency room physician, succeded by a computed tomography (CT) scan of the head, and then a consultation with an on-call neurologist who watches the emergency room nurse perform the National Institute of Health Stroke Scale (NIHSS) using a video camera, and a decision is made whether or not to treat with tissue plasminogen activator (tPA).

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The NIH Stroke Scale (NIHSS) has been shown to remain reliable and effective when administered via interactive video, supporting its use in telemedicine settings.[30] NIHSS assessment of stroke patients using telemedicine is as performance as face-to-face assessment.[31] There are fundamentally three telestroke network models: hub-spoke, distributed model and the hub-less model. In the hub-less model physicians that belong to different institutions take telestroke calls on a rotatory basis to provide regional coverage.

Hub and spoke and distribution models are the paramount used models within telestroke and both models are described by the AHA/ASA as commonly used in telestroke.[32] The hub-and-spoke model refers to a network that is consisting of a central "hub" site, such as primary or comprehensive stroke center, that then supply telestroke care to other healthcare centers, or "spoke" sites, within a specified catchment or geographical area.

The hub is typically a comprehensive tertiary care center, where telestroke consultants are based. In addition to 24-7 coverage by specialists in ischemic stroke, hub resources typically also comprehend neurosurgeons who can surgically manage intracranial hemorrhages, endovascular specialists who can perform angiography and its related interventions, and stroke/neurocritical care units. Spoke hospitals are small or mid-size facilities in rural or remote areas that lack direct neurological resources and expertise, must have the means to transfer patients requiring a higher level of care, such as endovascular surgery or admission to an intensive care unit or stroke unit, to the to the hub hospital. Typically, a central hub hospital usually offers round-the-clock stroke care to multiple spoke hospitals within a regional network. The hub-and-spoke telestroke network evidenced significant efficacy in delivering timely, specialized stroke care across a large and diverse patient cohort.[33]

An alternative network model, the "distributed" model a decentralized telemedicine service (either an independent for-profit company or an organized group of providers) workers telestroke providers at distant sites to provide hospital consultations through contracted services. This model delivers telestroke services to several sites via an independent corporation or a network of affiliated providers.[27] In other words, multiple providers—potentially spanning various healthcare systems—are integrated within a network to deliver telestroke services to additional sites in need, such as hospitals, clinics, mobile stroke units, and other facilities. The term "Drip and Ship" refers to transferring patients from spoke to hub sites after the bolus dose of tPA and transferred emergently for further management.[34] Participation in a telestroke network may improve acute stroke care metrics, as shown by faster last-known normal needle and door-to-needle times at spoke sites.[35] This may be secondary to improved procedure in stroke management, educational initiatives, and training that can be directed by the hub site.

Telestroke in the emergency department

When a patient arrives at the emergency department (ED) of remote hospital, emergency teams must promptly identify acute neurological deficits and characterized as "code stroke. Thus, patients receive immediate, hands-on care and assessment from the expert doctors and nurses on staff, and participating sites' ED personnel are prepared to complete National Institutes of Health Stroke Scale (NIHSS) assessments.

Medical staff at remote sites need to be trained for ever evolving telestroke protocols. Once the patient is brought into the ED the key diagnostic test is a CT scan of the brain. However, radiologists are currently in short supply worldwide, which means that the likelihood of having a radiologist on site in a hospital at the same time as a patient arrives cannot be guaranteed. With two-way video and audio communication systems, these centers connect experts in stroke neurology and interventional neuroradiology to consult on stroke management including reperfusion by IVT and EVT. Systems incorporating video consultation seem to be superior to telephone consultation alone.[36]

According to the American Heart Association/American Stroke Association 2018 guidelines, there is a paradigm shift from "Time is Brain" to "Imaging is Brain" in acute stroke management.[37] In fact, most telestroke systems have the ability to transmit protected DICOM (Digital Imaging and Communications in Medicine) images via a server. Therefore, a certified neurologist located remotely, can make a rapid assessment of suitability and administration of alteplase therapy. Time to treatment from the onset of stroke symptoms is perhaps the most important factor for the best outcomes.

Delays in transport of patients to tertiary care centers can lead to loss of the crucial intervention time window in acute ischemic stroke patients. Reducing Door-to-Needle (DTN) time (time taken from the arrival of the patient at the ED doors to administrating thrombolytic therapy to the patient) for thrombolytic therapy is particularly challenging at sites lacking onsite neurology coverage. Consensus between central read and each of spoke radiologists and hub vascular neurologists in interpreting head computed tomography (CT) scans of stroke patients presenting to telestroke network hospitals is reliable in differentiating between ischemic stroke and hemorrhage stroke.[38]

Furthermore, candidates for thrombolysis must be chosen not only based on time windows, but above all based on vascular and physiological information. Distant stroke experts can gain insight into cerebral blood flow and vascular physiology by viewing multimodality CT, including four-dimensional CT angiography and CT perfusion (4D CTA-CTP), which offers a detailed evaluation of collateral circulation and morphological in AIS.[39] As a result, advanced Imaging Techniques in Neuroradiology can also help identify the blocked vessel and estimate the amount of brain tissue at risk of damage.

Notably, collateral circulation is not only the main factor deciding the final infarct volume and ischemic penumbra of AIS, but also the major factor influences the final functional outcome of patients with EVT. Cerebral collateral circulation is now increasingly recognized as a key factor in the management of acute stroke.[40] Neurologist located remotely can apply the Alberta Stroke Program Early CT Score (ASPECTS). This is a quantitative approach to estimate the volume of early ischemic changes in acute stroke. It was created to evaluate highly acute cases (within 3 hours of symptom onset) and estimate the success rate of thrombolytic therapy.[41]

ASPECTS is a reliable tool to assess the extent evaluation and quantification of early ischemic changes by stroke neurologists in telemedicine in real time. Intercoder reliability agreement between neurologists and neuroradiologists in ASPECTS interpretation has been reported in telestroke programs, without influential implications on outcomes.[42] With the support of the telemedicine network, endovascular treatments can be provided to candidates with ischemic stroke transferred from primary telestroke centers in rural areas with outcomes like those of patients admitted directly to highly specialized comprehensive stroke centers.[43]

In intracranial hemorrhages, telestroke networks help select patients requiring advanced neurosurgical care.

For instance, in the event of a hemorrhagic stroke arriving at a rural hospital lacking neurosurgical expertise, telestroke specialists

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can help identify patients who are candidates for stabilization and emergency transport to comprehensive stroke centers for timely neurosurgical and neurocritical care, improving the quality of stroke care.[44]

Artificial Intelligence in Stroke Imaging is the exciting area in diagnostic radiology today. Since radiological images today are digital/binary, computer analysis using classical machine learning and deep learning algorithms can be applied to stroke, it is possible to detect specific patterns. Indeed, AI-assisted diagnosis and management methods for ischemic strokes and vascular occlusions are emerging.

Additionally, for early diagnosis of cerebral strokes, including CT and MRI scans, deep learning model-VGG16 for feature extraction has been integrated with Support Vector Machines (SVM) for categorization, assessed on a data set of annotated brain scans, attains an accuracy of 96.50 % .[45] Furthermore, deep learning (DL) models, due to their sophisticated data processing capabilities, are effective for immediate stroke management and prediction.

Application of the DL model improves timely stroke diagnosis, automated calculation of the Alberta Stroke Program Early CT Score (ASPECTS), large vessel occlusion (LVO) detection, ischemic prognosis, and imaging outcome prediction.[46] However, the use of artificial intelligence in stroke management and prediction requires further study to guide future decision-making.

Telestroke in prehospital stroke care and mobile stroke units (hyper-acute telestroke network)

Access pre-hospital telestroke care helps hospitals overcome time lost to prehospital delays through timely access to stroke care experts. There are, of course, many instances in which disparities in technology access remain a challenge. Even socioeconomic inequalities in prehospital stroke care have been found, for instance, lower socioeconomic status was found to be associated with prehospital delays.[47] Of all the main challenges in stroke care is the on-site prehospital clinical assessment of patients with suspected acute stroke to optimize subsequent diagnostic and therapeutic pathways.

Pre-hospital triage of patients can be performed by initiating a request for pre-hospital assessment via real-time end-to-end encrypted audio and video streaming from the pre-hospital setting to an in-hospital physicians' clinical expertise. Obviously, only the remote presence of a neurologist, with specialized expertise in acute stroke management, can assist rural hospital physicians in the complex medical decision-making process, such as facilitating timely diagnosis and triage decisions, secondary hospital bypass, and treatment.[48] It is assumed that acute stroke care must begin in the prehospital setting, so effective prehospital care is an integral part of the overall stroke care system. To implement early therapy and better outcomes, prehospital stroke care needs to be streamlined.

Several studies have identified and evaluated the effects of individual strategies to improve stroke care processes, over the entire stroke rescue chain with the goal of improving access to highly effective time-sensitive treatment, as specified below. The earlier the treatment is given, the greater the chance of recovery. It is known that the first-time reference point is from arrival to the start of obtaining the CT scan within 15 min, which is door-to-imaging time (DTI).

The second time standard is the time from arrival to the administration of thrombolysis within a median 30 min, which is door-to-needle time (DNT), and the third benchmark is to achieve a median time from arrival to the start of EVT within 60 min, which is door-to-groin puncture time (DGPT).[49] Now, the primary effort is directed toward pre-hospital delays by training pre-hospital staff and using emerging technologies.

One of the most remarkable progresses in the treatment of acute stroke within the last decade certainly was the emergence; of mobile stroke units (MSU). MSUs are ambulances provided with a CT-scanner for brain imaging, CT angiography, a point-of-care laboratory, a telemedical interface and a medical staff and there is abundant evidence that showed improved functional outcomes use of MSU.[50]

MSUs may enable faster treatment with tissue plasminogen activator (t-PA) than usual handling by emergency medical services.[51] Therefore, if a stroke is confirmed on-site, MSUs allow pharmacological therapy for ischemic and hemorrhagic stroke ultra-early initiation, as well as targeted and direct hospital transfer of patients requiring further endovascular treatment. As indicated earlier, MSUs have been shown ameliorate outcomes and have the potential to revolutionize prehospital stroke care.[52]

MSUs improve stroke care metrics such as treatment initiation, "golden" hour thrombolysis rate, thrombolysis rate, and triage to the required level of care.[53] This short window of time allows entails no risk to the patients' safety and is associated with better short-term outcomes. Compared with usual care, MSU use was associated with an approximately 65% increase in the odds of excellent outcome and a 30-minute reduction in onset-to-IVT times, without safety concerns.[54] Cost-benefit analyses have been conducted in several countries, and the results have suggested an acceptable cost-effectiveness ratio of using MSU.[55] Prehospital stroke management in MSU is associated with a significantly lower level of global disability at hospital discharge.[56] At present, based on the results, access to pre-hospital management of MSUs should be expanded.

Stroke network in northern Italy: Lombardy region

The territorial emergency–urgency system of the Lombardy region is coordinated by the Regional Emergency Urgency Agency (AREU). A structured, regional hub-and-spoke model of stroke care is used, with specialized "hub" hospitals and "spoke" coordinated by AREU, a single institution responsible for coordinating the entire emergency transport system. In the Lombardy, the stroke network obviously has as its primary objective the implementation of an integrated care model capable of overcoming territorial inequalities to guarantee all stroke patients the best possible care.

The Lombardy Stroke Network, established with Resolution of the Regional Council No. XI/7473, 22/11/2022.[57]

In general, stroke Network is organized into functional units made up of Comprehensive Stroke Centre (level II Stroke Unit) and one or more Primary Stroke Centres (level I Stroke Unit) and hospitals with an emergency department but not equipped with a Stroke Centre. It should be further commented that in Stroke Network, Level II Stroke Unit is the coordinator of the Functional unit.

The main difference between the two levels is the possibility of performing endovascular recanalization procedures, comprehensive stroke centers are required to provide permanent accessibility to EVT. It is expected that angio-CT and perfusion CT will be present at both levels with teleradiology support from level II center. The functional units aim to guarantee a 24-hour neurological assessment, the presence of software for the automated calculation of the ischemic

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penumbra (CT/MRI), a neuroradiologist/teleradiology system for the interventional neuroradiology consultancy.

Among the current Mothership, Drip&Ship, Drip&Drive and Mobile Stroke Unit models, in the Lombardy Region, due to its geographical, demographic, organizational and personnel availability characteristics, new strategies include direct transportation of patients to a comprehensive stroke center or transportation to the nearest primary stroke center and secondary transfer to the comprehensive stroke center. The Mothership model provides for primary centralization to the Level II Stroke Unit (Hub), and the Drip&Ship model, in which transport by emergency vehicles to the nearest Level I Stroke Unit (Spoke) is possible for Intravenous Fibrinolysis, with secondary centralization only if there is a large vessel occlusion susceptible to mechanical thromboembolism.

However, a careful evaluation of the transport and administration times of recanalization therapies at individual centers can help in identifying the most appropriate model.

The Italian guidelines suggest preferred that in the absence of supporting evidence, the Mothership model is to be preferred when the transport time to the level II centre is less than 30-45 minutes while the Drip&Ship model is to be preferred when this time is greater than 45 minutes provided that the DTN time of the level I centre is less than 60 minutes.[58]

The Regional Emergency Agency of Lombardy created two regional maps: one map with a cut-off for the travel time from the Spoke to the Hub <30 minutes and the other <45 minutes. If the time on the road was >60 minutes, the activation of the helicopter rescue with transport to the closest Level II Stroke Unit was planned.

Conclusion

The telestroke network can improve stroke care by including links between hospitals and play a central role in the treatment a patient receives, particularly in IVT reperfusion. Over the past few decades, there has been a significant expansion in the implementation of telestroke technology worldwide, increasing the population's access to expert neurologists in the event of acute stroke symptoms. Looking ahead, the goal is for telestroke to enable rural hospitals to provide care equivalent to that of hospitals with dedicated stroke specialists.

Of course, with the remarkable advance's innovative healthcare solution, telestroke not only saves crucial time but also amplify, the reach of stroke specialists to communities previously underserved. It is noteworthy that more work is required in low-and middle-income countries (LMICs) to implement telestroke services and sustain access to stroke reperfusion therapies.

Telestroke networks may represent an option to address the challenge of providing skilled stroke care, resulting in higher IVT rates, higher rates of skilled stroke care, and lower rates of onward transfers. Today it is as true as it ever was, however, that remains a critical need for universally applicable guidelines that can be adapted to diverse resource settings to make certain that all patients with stroke receive guidelines-concordant, time-sensitive care.

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Conflicts of interest

The author declares that there are no conflicts of interest.

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