Future Neurohospitalist: Teleneurohospitalist

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Abstract

Despite the growing demand for emergency neurological evaluations and neurohospitalists, the supply of neurologists remains relatively fixed over time. Telemedicine is a unique tool that has the ability to put a medical specialist like a neurologist in 2 places in a relatively short period of time, expanding expertise in many rural and in some underserved urban facilities that would ordinarily be devoid of such expertise. Teleneurology is a branch of telemedicine that consults and practices through remote neurological evaluation. Telestroke is defined as remote stroke evaluation. The demand for timely neurological evaluation, especially acute stroke evaluation and treatment with intravenous recombinant tissue plasminogen activator (IV rtPA), continues to fuel the growth of neurohospitalists, telestroke, and teleneurology services. Remote, rural, or underserved urban emergency departments and hospitals which are unable to successfully recruit a neurologist or neurohospitalist to provide this service are uniquely suited to a teleneurology option. The number of private practices and academic centers providing telestroke services has grown significantly in the past decade with continued growth expected. We describe the benefits and drawbacks of teleneurology/telestroke, as well as other practical aspects for the teleneurohospitalist.

Keywords

neurohospitalist, clinical specialty, hospitalist, telemedicine, teleneurology, future neurology

Introduction

Neurohospitalists are site-specific neurological specialists who are dedicated to the hospital environment and evaluate emergency department (ED), critical care unit, and medical-surgical patients with various neurological conditions.¹⁻⁵ The growth facing the neurohospitalist profession is fueled by demands within the American health care system for timely evaluations of patients with acute stroke and other neurological disorders within the ED and hospital.^{1,2} The aging of the US population is expected to cause a relative peak in demand for neurological services within the next 5 to 15 years^{4,6} and lead to further increased demand for inpatient neurological expertise. The overall supply of neurologists has been trending upward in recent years (Figure 1) but still may not eliminate the supply and demand mismatch for neurological expertise at the hospital.⁴ It is unlikely that enough neurologists will become neurohospitalists to confront the neurological inpatient demand.

Sufficient neurological expertise is unlikely to be generated in a short period of time, since neither the specter of declining reimbursements to neurologists nor the cuts in Medicare-funded resident training⁸ are likely to lead to an increase in

neurology training positions sufficient to match this future demand. Teleneurology/telestroke services are technologically feasible solutions to bridge this supply and demand gap, and, in fact, are already being provided at multiple sites in the United States, utilizing both academic and nonacademic practice models.⁹⁻¹⁵ There are legitimate concerns, however, about teleneurology and telestroke services, including their potential impact on private sector or locum tenens work for other neurologists,⁹ and the constraints of a robotic examination compared to a standard bedside face-to-face neurological examination¹⁰ for interviewing and diagnosing a patient with a neurological presentation. This article focuses on the futuristic yet realistic use of teleneurohospitalists to bridge, partly,

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Figure 1. Supply of graduating adult US neurology residency graduates from US and International Medical Schools (IMG) from 1989 to 2010. Adapted from Data from Annual Education Issues 1989-2010.⁷

the future inpatient care gap, as well as the realities of the technological limitations and financial (business) considerations for practicing neurologists and neurohospitalists.

Future Neurohospitalist: Teleneurohospitalist and Telestroke Services

A teleneurohospitalist is a neurohospitalist who provides teleneurology services to an ED and/or a hospital located remote to their immediate geographic physical practice. *Teleneurology* is a subset of the larger practice of *telemedicine*, which uses real-time audiovisual communication to provide a doctor-patient interaction and evaluation suitable for medical decision making and recommendations.¹¹ Teleneurology represents a viable practice extension for a neurologist whether one is an inpatient specialist, that is, neurohospitalist or neurointensivist, or based in the outpatient setting.¹¹ Even though the focus of this article is primarily the inpatient setting, teleneurology literature has demonstrated feasibility in evaluating general and subspecialty neurology outpatients including those with dementia, headache, epilepsy, neuroophthalmological complaints, neuromuscular diseases, and Parkinsonism.¹⁶⁻³⁸

Telestroke is a subset of teleneurology, which focuses on the evaluation of patients with acute stroke syndromes for possible intravenous recombinant tissue plasminogen activator (IV rtPA) administration or other emergency stroke treatments. Telestroke has developed rapidly and has accumulated a large body of evidence-based literature supporting its use in evaluating patients with stroke remotely.¹¹⁻¹⁵

Given the current high demand, based on job postings,^{1,2} for neurohospitalists and neurological services at the hospital, we predict similar future high demand for teleneurology and telestroke services. Additionally, telestroke and teleneurology services reflect viable practice options not only

for neurohospitalists but for other neurologists to help bridge the supply and demand mismatch between neurological expertise at the hospital and may even help provide financial support to a neurological practice's bottom line.³⁹ Further financial implications, as well as potential benefits to patients, the referring ED physicians, and the hospitals, are discussed below.

How Can Teleneurohospitalists Impact Patient Care?

The decision to treat patients with acute ischemic stroke in the ED or hospitalized setting with IV rtPA within 3 to 4.5 hours of symptom onset is an example in which having the neurological knowledge base and practice experience matters and results in enhanced quality care delivery and outcomes. In a survey of 278 ED physicians from 24 hospitals, 65% of physicians reported feeling uncomfortable giving IV rtPA without a consultation.⁴⁰ Despite Food and Drug Administration (FDA) approval of IV rtPA in 1996 for acute ischemic stroke, rtPA utilization rates in the United States remain low, with only ~2% to 5%⁴¹ of patients being treated despite their apparent eligibility for rtPA.⁴² Telestroke/telemedicine data suggest that remote acute stroke patient examinations at rural hospital settings are feasible and have good inter-rater reliability compared to those of a face-to-face on-site examiner.⁴³⁻⁵³

Teleneurology and telestroke do have certain barriers, legal issues, credentialing, and technical limitations that must be mentioned, however.⁵⁴ Barriers for setting up a telemedicine network for remote stroke evaluation include conceptual distrust among the referring hospital system (physicians, administrators, nurses, etc) and concern on the part of consulting neurological subspecialists unfamiliar with the sophisticated system that it may not provide a reliable and secure consultation portal.⁵⁴⁻⁵⁷ Over the past decade, the technological

Figure 2. Telestroke/telemedicine network concepts. A, Telemedicine robot from commercial vendor⁶³ which is typically controlled via a computer base station which functions over high-speed Internet network. A laptop with Internet capability can also control and view the robot the same way. B, Image of a patient with a subarachnoid hemorrhage, with a right external ventricular drain. The imaging is seen remotely via mobile phone (iPhone) and Virtual Private Network (VPN) via cell phone carrier (AT&T in this case) to review imaging without a base station or a laptop.

limitations have become increasingly less relevant in telestroke evaluations performed with a simple videoconferencing camera, a mobile iPhone Facetime evaluation, or when using a complex third-party robotic device that integrates videoconferencing with advanced optics and neuroimaging integration (albeit at higher costs).⁵⁷⁻⁶² Figure 2 demonstrates some of the technical aspects of telestroke and teleneurology, in general such as the Robot and remote viewing of stroke imaging on a mobile device. Figure 3 demonstrates a telestroke robot encounter on a patient with a right middle cerebral artery territory infarction and drift of the left arm compared to the right which was dramatically improved compared to preintervention.

Telestroke has been shown in several clinical studies⁶⁴⁻⁷⁴ to have feasibility and safety,⁶⁵ acceptable inter-rater reliability of the virtual examination versus physical bedside examination,⁶⁵⁻⁶⁷ increased thrombolysis treatment rates, improved clinical outcomes,⁷⁵⁻⁷⁹ cost-effectiveness,⁸⁰ and enhanced opportunities for referring centers to gain stroke center designation status.^{81,82}

Telestroke is particularly advantageous to the rural, underserved ED or hospital,⁸³⁻⁹⁰ which may be challenged in recruiting specialists in relative short supply, including neurologists and subspecialists such as neurohospitalists, neurointensivists, and vascular neurologists.

Beyond Telestroke: Teleneurology at the Hospital

Telestroke remains one of the best studied and validated models for telemedicine. The utilization of a standardized examination such as the National Institutes of Health Stroke scale (NIHSS) with established inter-rater reliability when performed remotely has played an important role in the success of remote stroke evaluation.^{91,92} Standardized scales for examination of patients with nonstroke diagnoses or symptoms have yet to be developed.⁹³⁻⁹⁶ Remote evaluation does not allow the examiner to appreciate the differences in tone or reflexes that may differentiate between upper or lower motor neuron localization in a patient with bilateral leg weakness. The variability or distractibility that often accompanies functional signs may be difficult to appreciate with a remote evaluation. Although an experienced bedside provider working in concert with the teleneurohospitalist can elicit and improve interpretation of neurological signs, current technologies, even with expensive, commercial robots, do not provide the capability to examine patients the same way as a standard bedside neurological examination and tools in the outpatient setting.⁹⁶

Remote evaluation of patients in the ED and hospitalized setting via teleneurology has been shown to be feasible⁹⁵ and

Figure 3. Example of Robotic telemedicine encounter of a 66-year-old female with a right MCA-MI ischemic stroke, status postendovascular intra-arterial clot retrieval with suction device on postprocedure day #1, asked to give “2 thumbs-up” which shows left thumb having downward upper motor neuron drift. Her formal National Institutes of Health Stroke scale (NIHSS) was a 4 (1 for left facial droop, and 1 for left arm downward drift) and 2 for hemibody sensory loss, including 1 point for extinction. She presented with an NIHSS of more than 7 and was globally aphasic (she was left handed) but had complete normalization on NIHSS by hospital day #2 (NIHSS = 0).

safe similar to telestroke. Similar to telestroke triage for stroke, one could envision rapid adoption of teleneurology to help evaluate patients without stroke such as encephalopathy or seizure disorders. In these cases, the history is critical to diagnosis and the neurological examination may be normal—a perfect scenario for effective utilization of remote telepresence technology. Headache disorders and symptoms affecting speech or language also have the potential to be effectively evaluated by a teleneurohospitalist. Teleneurology may be of particular value in underserved rural areas or in developing countries which otherwise would be without any neurological expertise,⁹⁷⁻¹⁰⁹ and provides similar benefits of earlier evaluation especially of acute neurological disorders other than stroke, such as spinal cord injury^{110,111} and even epilepsy.¹¹² The critical care unit is another domain where robotic telepresence or teleneurology serves to monitor critically ill patients, evaluate unexplained coma, and respond quickly to unstable patients.¹¹³⁻¹¹⁵

Table 1 demonstrates a comparison between the typical bedside or clinic neurological examination and the robot examination or teleneurology examination. Table 2 outlines in detail the cranial nerve examination performed via robotic/teleneurology versus that conducted at the bedside or in the clinic. The tables are provided as a general overview to the general practitioner to understand how the neurological examination is performed via telemedicine, since most practitioners know the basics of the comprehensive neurological examination. The telestroke examination typically uses the

NIHSS, which can be augmented or supplemented by additional features displayed in Tables 1 and 2 if the patient is suspected to have a diagnosis other than stroke. Pupils, for example, can be assessed with a bedside pupil gauge¹²⁰ to measure size in millimeter (mm), and there are newer infrared computerized pupillometers (Figure 4) that can measure the pupil size down to the sub millimeter range, can grade pupillary reactivity¹¹⁶ undetectable to the naked eye, and can detect raised intracranial pressure¹¹⁷ and other disease states.¹¹⁸

Business and Practice Implications of Telestroke and Teleneurology

Telestroke and teleneurology are potentially disruptive technologies in the sense that the innovation itself may create a new market or even overturn the existing dominant technology in the market over time.¹²¹ Telestroke and teleneurology have shown rapid growth and require mutual adaptation within the existing technological, administrative, legal, and financial systems of health care delivery. The essential considerations for both hubs and spokes are (1) coverage and practitioner availability, (2) type, suitability, reliability, and security of the network and technology, (3) start-up and maintenance costs, (4) reimbursements for teleneurology services, (5) professional licensure requirements, (6) legal risks and professional liability, and (7) relationships and responsibilities.

Coverage and Availability

Coverage of an additional remote ED or hospital adds considerable work and time requirements to the on-call duties of any neurohospitalist or neurologist. There are several key considerations. The first is *practice integration*, or whether or not the accepting hub neurological practice can assume 24/7/365 on-call responsibilities for the referring center (ED or hospital), similar to physically covering call for that hospital or ED. For smaller neurology/neurohospitalist practices that cannot assume continuous on-call coverage, it may be worthwhile to consider waiting until that practice has enough partners to cover these services continuously. Another alternative is to tailor telemedicine coverage to spoke hospitals only for specific services (eg, acute stroke, paraparesis or quadriparesis, status epilepticus) or designated time intervals (eg, nights and weekends).

For example, several of the underserved communities for which the authors supply telestroke services have only a single neurologist. The community neurologist provides principally outpatient services during the day and arrives at the regional medical center later to conduct consults on inpatients, preferring not to take emergency calls after hours. This is not an uncommon scenario, nationally, when there is no designated call pay for stroke or other neurological emergencies. The local hospitals cannot, typically, obtain their primary stroke center designation due to these restricted staffing constraints. The addition of a telestroke service provided by Mayo Clinic

Table 1. Comparison of the Neurological Examination Components Able to Achieve via Teleneurology (Robotic or Virtual) Versus Real or In Person

Examination	In Person	Robotic (Virtual)
NIH Stroke Scale	Yes	Yes ^a
Mini-Mental Status Examination	Yes	Yes ^a
Cranial nerves	Yes	Yes, partial ^a (Table 2)
Language	Yes ^b	Yes (if audio functional) ^b
Motor examination	Yes	Yes, MRC ^a or NIHSS (stroke)
Reflexes	Yes	Yes, ^a but observational
Gait	Yes	Yes ^a

^a A trained bedside nurse, nurse practitioner, or physician may be necessary to help complete these parts of the exam (eg, for the National Institutes of Health Stroke scale (NIHSS), for a paretic limb the patient may need active assistance from someone in the room raising the paretic limb to test whether it is antigravity or resistance, etc).

^b Deaf, aphasic, and encephalopathic patients may be difficult to communicate with, either virtually or in person. Also, for the Mini-Mental State Examination or the NIHSS written section, the handwriting component will require someone to hand the patient pen and paper and so on. Cranial nerve examination can be optimized if there is adequate optical resolution to look at a patient's pupils when someone shines a light on them (direct and consensual) and further objectified with pupillometry devices.¹¹⁶⁻¹¹⁸ Funduscopy examination is not feasible with most robotic examinations, although a Panoptic connected to a personal digital assistant and used locally can then be shown to the remote teleneurologist.¹¹⁹ A bedside nurse or physician can perform corneal reflexes, doll's head response, gag, and suctioning under supervision with adequate training and instruction. Motor examination by the Medical Research Council (MRC) grades is possible if the patient can follow commands and can be classified as either >3 or <3 (antigravity or not), and if a person is there, preferably a registered nurse (RN) or physician, some gauge of resistance can be made (4/5 near normal resistance, 5/5 = normal strength). Reflexes are limited in teleneurology due to the lack of consistency of hands-on examination and of the type of hammer and force applied to the deep tendon reflex. However, DTRs can be observed or performed by a trained local examiner such as another physician. Gait depends on the initial examination if the patient is already supine in the hospital or emergency department bed. For real-time gait testing, the practitioner's judgment should prevail (eg, hemiplegic, comatose patients have questionable benefit for gait challenge). In general, it is suggested to have someone or several capable people in the room to prevent falls, especially for hemiparetic or other neurological patients, for example, ataxic or neuropathic patients who might fall, for example, during Romberg testing. The same fall risks are present in these patients and should be given the same level of fall prevention precautions as if an examiner were there in person. Also, when in doubt about a particular aspect of the neurological examination that is crucial to the correct diagnosis, one should consider transferring the patient from the spoke to the hub institution, if feasible, for more detailed neurological examination.

neurohospitalist division made it possible to accommodate the referring hospital's ED stroke call coverage. The practice of covering stroke-only patients requires considerable planning, education, and establishing of protocols for ED physician and nursing personnel regarding telestroke hotline activation criteria. For example, some telestroke networks adhere purely to the 3-hour or extended 4.5-hour IV rtPA eligibility criteria to simplify triage for the local and referring teams, while others have been more inclusive to evaluate or make recommendations on patients with acute stroke within 12 or 24 hours of symptom onset. Obviously, the more restrictive the criteria

the less likelihood of telestroke alerts or calls being activated. In this example, a patient who presents to hospital a day after the stroke onset is simply admitted to a medical hospitalist service and receives a routine physical consult the next day with the local neurologist. This allows a synergistic interplay between the virtual acute telestroke team and the local community practice neurologist. Additionally, the local neurologist, rather than the telestrokeologist, can potentially be consulted for stroke mimic cases (eg, in instances of seizure and postictal hemiparesis). For rural areas without a local neurologist at all, those spoke centers may consider transporting the patient to the hub center providing the telestroke services for a more comprehensive neurological evaluation.

Type, Suitability, Reliability, and Security of the Network and Technology

The second major consideration in providing a telestroke or teleneurology service is the *technology and network* used to provide the service to the referring ED or hospital. The number of commercial vendors providing telemedicine platforms and networks for this technology has grown dramatically and is outside the scope of this article. The reader is referred to some online references^{63,123} to research the various robotic technologies and audiovisual conferencing technology, all of which is in constant flux due to the ever-advancing technology. The American Telemedicine Association (ATA) resource⁶³ provided has a nice overview of such services, but the reader is advised that this site has both simple vendors for technology and full-service technological consulting firms. For example, if one is interested in starting a telestroke or teleneurology service but only needs the technology to do so, a simple digital audiovideo conference call camera,⁵⁹ the iPhone 4 for telestroke,⁶¹ or more expensive (full service) robotic platforms are commercially available, such as the InTouch Health^{60,62,123} platform or REACH platform.^{62,73,124} The reader should be aware that although the ATA Web site is referenced as a simple overview site, some of the telemedicine resources listed there, such as Specialists on Call and Neuro-Call, also offer complete or full service teleneurology services. These corporations provide a complete clinical teleneurology service to areas in need, and not just the technology, as in the case of InTouch or REACH, for neurologists willing to interface with another hospital or ED.

Two issues to consider under the technological aspects are network *reliability* and *security*, the importance of which cannot be overstated. For example, the network used in performing an emergent stroke consult must be highly reliable, and the service should have rapidly responsive 24/7 on-call tech support in case the connection is lost. For example, while a basic webcam service is simple and low cost, and fairly feasible with modern day off-the-shelf USB webcams, the issue of who will be able to service that webcam or network 24/7/365 must be considered if it is unplugged, or if technical problems arise in the middle of the night during a consultation

Table 2. Comparison of the Neurological Examination Components Able to Achieve via Teleneurology (Robotic or Virtual) Versus in Real (vis-à-vis)

Examination	Bedside Examination	Robotic (Virtual) Exam/Finding
Cranial nerves		
II	Pupil light reflex Reactivity, size Visual acuity card Funduscopy	Normal or abnormal ^a , pupillometry ^b or Pupillometry, ^b pupil gauge ^b grade each eye ^b Panoptic images ^b
III	Extraocular movements (EOM)	Gaze paresis, ^a CN palsy
IV	EOM to commands	Head tilt, ^a or Sogg's sign
V	Facial sensation, corneal reflex ^b	Absent or present ^b
VI	EOM to command	EOM ^b weakness
VII	Facial strength	weak vs. normal, ^b NIHSS, Peek sign
IX	Palate elevation	normal or Mallampatti ^a
X	Palate elevation	normal or weak ^a
XI	Shoulder elevation, head turn	normal or abnormal ^a
XII	Tongue protrusion	normal or abnormal ^a

^a Requires sufficient robotic optics and image quality as well as optimal patient and examiner positioning relative to each other.

^b Requires remote examiner to perform with patient (eg, bedside RN or MD). Pupillometry—infrared computerized measurement of the pupil (used in ophthalmology clinics and more recently bedside handheld devices^{115,116,120}). Panoptic device connected to computerized handheld such as iPhone (iExamine—IntuitiveMedTech¹²¹). NIHSS = NIH stroke scale facial weakness (0 = normal; 1 = minor; 2 = partial; 3 = complete weakness). Head tilt sign usually a leftward or rightward subtle head tilt suggestive of cranial nerve IV palsy of uncertain chronicity (usually chronic/congenital). Sogg's sign, forward head tilt in bilateral cranial nerve IV palsies. Peek sign = inability to close the eyelid, usually seen in peripheral (not central) causes of facial weakness such as Bell's palsy, myasthenia,¹²² or Guillain-Barré.

Figure 4. Pupillometer images viewed from the telemedicine robot: normal pupil reactivity or “smile” (left image). Right image shows “flat-line” or fixed-dilated (unreactive to manual inspection and pupillometer-derived neurological pupillary index, NPI¹²⁰ shown as “-” which is nil) bilateral pupils (right is 4.38 mm and left is 5.23 mm) in a patient with massive ischemic stroke with uncal herniation who later was pronounced brain dead by formal American Academy of Neurology (AAN) criteria.

either remotely or locally. There are also security issues for physicians in terms of Federal patient health care privacy laws such as Health Insurance Portability and Accountability Act (HIPAA) over such a network, many of which are encrypted and secure using secure socket layer (SSL) or https encrypted services.^{124,125} Another consideration for telestroke and teleneurology is neuroimaging access, in particular the remote viewing of simple neuro- and more advanced neurovascular imaging of such patients. Some of these companies offer integrated picture archiving and communication system

(PACS) at an incremental fee,¹²⁵ while other hospitals are able to grant similar remote (once credentialed) access to imaging similar to that provided to their local physicians,¹²⁶ which can then be accessed separately from the robotic or audiovisual telestroke or teleneurology encounter.

Start-Up and Maintenance Costs

A third major consideration is the *costs* of start-up and maintenance for telestroke and teleneurology services. What is the

Table 3. Pros and Cons of Teleneurohospitalist Model

Pros	Cons
Timely access ^{4,105}	Costs (start-up and maintenance)
Improved IV-rTPA utilization rates ^{64–89}	Need for 24/7/365 coverage
ED recognition of neurological disorders ^{99,109–112}	Network/technical/security issues
Helpful in rural and underserved areas ^{81,82,105}	Competition vs locum tenens
Potential for practice supplementation	Additional call responsibility

monthly cost for a fully serviced robot system from one of the commercial vendors?¹²³ Prices will vary based on the vendor, but one high-end estimate (in 2011) is between \$5000 and \$6000 per month for a single hospital mobile robot system with 24/7/365 network on-call coverage, with integrated security socket platform. There is also typically a large telemedicine base station installed that may cost in excess of \$10 000. Additional fees may apply, depending on the integration of PACS imaging and other software upgrades. Other emerging technological advances include lower cost systems,¹²⁶ personal digital assistant (PDAs),¹²⁷ the iPhone 4 Facetime platform, and other smartphones^{61,128,129} with or without integrated imaging or PACS (Figure 2B). Validation of these PDA systems in relation to the other larger, more expensive systems utilized in the majority of telestroke literature remains lacking, and the above references provide proof of concept in terms of weighing all the options for one's own telestroke or teleneurology program.

Reimbursements for Teleneurology Services

The fourth consideration for providers interested in telestroke and teleneurology is *reimbursement*. Reimbursement is highly variable depending on the health region or system for which telestroke or teleneurohospitalist services are being provided. Private hospitals, for example, may reimburse an academic or private practice telestroke/teleneurology system at a flat rate per month, with additional reimbursements for start-up costs involved in setting up the local and remote PACS security networks. Again, private entities such as Specialists on Call and NeuroCall are examples of corporations that leverage their services to EDs and hospitals in need in the United States. Other academic and private systems that offer these services to surrounding EDs and hospitals in need have reimbursements which are highly individualized based on the referring hospitals financial status (private vs indigent state institution) and their ability to afford or pay the referring service. Other telestroke or teleneurology systems may charge the patient, a method complex in and of itself due to variations in ED and hospital patient payer mix and percentage of Medicare patients, among other variables. Medicare currently reimburses telemedicine services in some but not all states, and the amount of reimbursement varies. Detailed reviews of reimbursement complexities for telestroke services have previously been published,¹⁴ which covers Medicare

reimbursement in greater detail. Some hubs (telestroke or telmedicine centers) receive a flat monthly rate from the referring spoke telestroke/teleneurology hospital directly which encompasses all encounters requested monthly, while others may charge services depending on volume (Table 3).

Professional Licensure Requirements

The fifth major consideration is *licensure* of the telestroke or teleneurology physicians at the hospital or ED for which they are providing services.^{12–14} Hospital licensure depends on the composition of the local hospital administrative board, the credentials of the physicians being credentialed, and whether the hospital in question is within the same state as the physician's state license. If the services are being provided in a state or country different from that in which the physician is licensed, the physician is typically required to obtain an additional license to practice medicine or the particular subspecialty, according to the state's or country's own requirements. After that process is approved, usually the local hospital or ED can initiate the local credentialing and licensure process.

Legal Risks and Professional Liability

The final issue is that of *litigation* involving telestroke or teleneurology service providers. From the American Heart Association/American Stroke Association Scientific statement on implementation of stroke systems of care from 2009, Schwamm et al write, "Ironically, the available evidence concerning litigation involving stroke therapy with tPA indicates liability is predominantly associated with failure to provide tPA rather than with adverse events associated with its use . . ." ¹² Regarding telestroke programs, there has been no specific evidence thus far to suggest that providing telestroke consultations increases the risk of malpractice claims compared to the risk of providing local consultations for the treatment of acute stroke patients. Providers should note that they might be vulnerable to legal action in both the originating state where the telestroke patient was located at the time and the state in which they provided telestroke consultative services.^{12–14} A very important issue for telestroke providers to remember is that when thrombolytic therapy is being considered in terms of acute stroke patient, the team of neurologists, ED physicians, and hospitals are at increased liability whether or not the decision is made to give tPA; and according to one study,¹³⁰ the clinical decision *not* to administer the therapy

requires detailed documentation of such rationale in the medical record. It is also suggested that informed consent discussions be documented (although not necessarily with a formal, written consent) and that timely transfer to a higher level facility be made, especially if there is a potential for salvageable intervention (eg, to a facility with a neurosurgeon if one does not exist at the spoke site) to help reduce the threat of legal action. Since telestroke services may actually increase the administration rates of rtPA at the spoke hospital, providers at both the spoke and hub should document the appropriate reasons why or why not rtPA was given to reduce medicolegal liability exposure, as well as effective communication among all telestroke team members.

Relationships and Responsibilities

Rules, principles, and contractual agreements should govern the services and interactions between teleneurohospitalist providers (at the hub hospital) and recipient referring clinical providers (at each spoke hospital). Agreements should address assignment of costs, compliance with government boundaries and noncompete relationships, medicolegal risk, malpractice coverage, sharing of protected health information, administration, licensing and credentialing, reimbursement for professional fees, expectations on both ends, protocols, care algorithms, education of providers, and roles and responsibilities.

Concluding Comments and Future Horizon

Telemedicine, telestroke, and teleneurology will continue to advance due to improvements in technology (more compact and faster), thereby enhancing the ability to perform remote patient assessment with smaller and more handheld devices over faster data and cellular data networks.¹³¹ This will enable more subspecialists to help underserved and rural hospitals in need of subspecialist expertise.

The future for telemedicine includes the involvement of other providers such as advanced nurse practitioners¹³² and the provision of additional educational framework for teaching neurology in other countries.¹³³ From the business side, telestroke and teleneurology offer an opportunity for neurohospitalists or teleneurohospitalists to expand their practice reach and to serve more patients. More research is needed in teleneurology with regard to other aspects of care, including a systematic review of the literature supporting the reliability, safety, and efficacy of telemedicine adapted to all the subspecialties of the clinical neurological sciences, the reliability of various components of the teleneurological examination typically performed by the neurologist at the bedside, patient-caregiver satisfaction, resource information,^{134,135} the extension of technology into the neurological examination such as transcranial Doppler for stroke patients,¹³⁶ telemedicine-facilitated recruitment of patients into acute stroke treatment trials,¹³⁷ and further elaboration

on which platforms meet FDA regulations.¹³⁸ Further technological innovations in telestroke and teleneurology will make it easier and more efficient for neurologists to evaluate imaging and patients via videoconferencing, even across continents.

Authors' Note

The study design; collection analysis, and interpretation of data; writing the report; and the decision to submit the report for publication was conducted solely by the authors of the study.

Declaration of Conflicting Interests

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References

1. Freeman WD, Gronseth G, Eidelman BH. Invited article: is it time for neurohospitalists? *Neurology*. 2008;70(15):1282-1288.
2. Josephson SA, Engstrom JW, Wachter RM. Neurohospitalists: an emerging model for inpatient neurological care. *Ann Neurol*. 2008;63(2):135-140.
3. Barrett KM, Freeman WD. Emerging subspecialties in neurology: neurohospitalist. *Neurology*. 2010;74(2):e9-e10.
4. Freeman WD, Vatz KA. The future of neurology. *Neurol Clin*. 2010;28(2):537-561.
5. Likosky D, Shulman S, Restrepo L, Freeman WD. Survey of neurohospitalists: subspecialty definition and practice characteristics. *Front Neurol*. 2010;1:9.
6. World Health Organization Report on Neurological Disease. http://www.who.int/mental_health/neurology/neurological_disorders_report_web.pdf.
7. Annual Education Issues. *JAMA*. 2010;304:1255-1270. 2009;302: 1357-1372. 2008;300:1228-1243. 2007;298:1081-1096. 2006;296:1154-1169. 2005;294:1129-1143. 2004;292:1099-1113. 2003;290:1234-1248. 2002;288:1151-1164. 2001;286:1095-1107. 2000;284:1159-1172. 1999;282: 893-906. 1998;280:836-845. 1997;278:775-784. 1996;276:739-748. 1995;274:755-762. 1994;272:725-732. 1993;270:1116-1122. 1992;268:1170-1176. 1991;266:933-943. 1990;264:822-832. 1989;262:1029-1037. 1988;260:1093-1101. 1987;258:1031-1040.
8. Dickler R, Shaw G. The Balanced Budget Act of 1997: its impact on U.S. teaching hospitals. *Ann Intern Med*. 2000;132(10):820-4.
9. Avitzur O. Is teleneurology replacing the neurologist. *Neurol Today*. 2010;10(15):1, 11-13.
10. Freeman WD, Vatz KA, Demaerschalk BM. Telemedicine in 2010: robotic caveats. *Lancet Neurol*. 2010;9(11):1046.
11. Patterson V. Teleneurology. *J Telemed Telecare*. 2005;11(2):55-59.
12. Schwamm LH, Audebert HJ, Amarenco P, et al. Recommendations for the implementation of telemedicine within stroke

- systems of care: a policy statement from the American Heart Association. *Stroke*. 2009;40(7):2635-2660.
13. Schwamm LH, Holloway RG, Amarenco P, et al. A review of the evidence for the use of telemedicine within stroke systems of care: a scientific statement from the American Heart Association/American Stroke Association. *Stroke*. 2009;40(7):2616-2634.
 14. Demaerschalk B. Telestrokeologists: Treating Stroke Patients Here, There, and Everywhere with Telemedicine. *Semin Neurol*. 2011;30(5):477-491.
 15. Capampangan DJ, Wellik KE, Bobrow BJ, et al. Telemedicine versus telephone for remote emergency stroke consultations: a critically appraised topic. *Neurologist*. 2009;15(3):163-166.
 16. Biglan KM, Voss TS, Deuel LM, et al. Telemedicine for the care of nursing home residents with Parkinson's disease. *Mov Disord*. 2009;24(7):1073-1076.
 17. Bremner F, Kennedy C, Rees A, Acheson J, Murdoch I. Usefulness of teleconsultations in neuro-ophthalmology. *J Telemed Telecare*. 2002;8(5):305-306.
 18. Adam OR, Ferrara JM, Aguilar Tabora LG, Nashatizadeh MM, Negoita M, Jankovic J. Education research: patient telephone calls in a movement disorders center: lessons in physician-trainee education. *Neurology*. 2009;73(10):e50-e52.
 19. Ahmed SN, Mann C, Sinclair DB, et al. Feasibility of epilepsy follow-up care through telemedicine: a pilot study on the patient's perspective. *Epilepsia*. 2008;49(4):573-585.
 20. Breen P, Murphy K, Browne G, et al. Formative evaluation of a telemedicine model for delivering clinical neurophysiology services part II: the referring clinician and patient perspective. *BMC Med Inform Decis Mak*. 2010;10:49.
 21. Chua R, Craig J, Esmonde T, Wootton R, Patterson V. Telemedicine for new neurological outpatients: putting a randomized controlled trial in the context of everyday practice. *J Telemed Telecare*. 2002;8(5):270-273.
 22. Chua R, Craig J, Wootton R, Patterson V. Cost implications of outpatient teleneurology. *J Telemed Telecare*. 2001;(7 suppl 1):62-64.
 23. Craig J, Patterson V. Introduction to the practice of telemedicine. *J Telemed Telecare*. 2005;11(1):3-9.
 24. Harvey R, Roques PK, Fox NC, Rossor MN. CANDID—counselling and diagnosis in dementia: a national telemedicine service supporting the care of younger patients with dementia. *Int J Geriatr Psychiatry*. 1998;13(6):381-388.
 25. Dorsey ER, Deuel LM, Voss TS, et al. Increasing access to specialty care: A pilot, randomized controlled trial of telemedicine for Parkinson's disease. *Mov Disord*. 2010;25(11):1652-1659.
 26. Duncan C, Dorrian C, Crowley P, Coleman R, Patterson V. Safety and effectiveness of telemedicine for neurology outpatients. *Scott Med J*. 2010;55(1):3-5.
 27. Hubble JP. Interactive video conferencing and Parkinson's disease. *Kans Med*. 1992;93(12):351-352.
 28. Hubble JP, Pahwa R, Michalek DK, Thomas C, Koller WC. Interactive video conferencing: a means of providing interim care to Parkinson's disease patients. *Mov Disord*. 1993;8(3):380-382.
 29. Jabre JF, Stalberg EV, Bassi R. TeleMedicine and Internet EMG. *Suppl Clin Neurophysiol*. 2000;53:163-167.
 30. Larner AJ. Use of the internet and of the NHS direct telephone helpline for medical information by a cognitive function clinic population. *Int J Geriatr Psychiatry*. 2003;18(2):118-122.
 31. Lea DH, Johnson JL, Ellingwood S, Allan W, Patel A, Smith R. Telegenetics in Maine: Successful clinical and educational service delivery model developed from a 3-year pilot project. *Genet Med*. 2005;7(1):21-27.
 32. Lengyel A. Neurology in the era of the Internet [in Hungarian]. *Ideggyogy Sz*. 2002;55(1-2):45-49.
 33. Lott IT, Doran E, Walsh DM, Hill MA. Telemedicine, dementia and Down syndrome: implications for Alzheimer disease. *Alzheimers Dement*. 2006;2(3):179-184.
 34. Pereira-Monteiro J, Wysocka-Bakowska MM, Katsarava Z, Antonaci F. Guidelines for telematic second opinion consultation on headaches in Europe: on behalf of the European Headache Federation (EHF). *J Headache Pain*. 2010;11(4):345-348.
 35. Rozza L, Tonella P, Bertamini C, Orrico D, Antoniol G, Castellaro L. Telephone transmission of 20-channel digital electroencephalogram using lossless data compression. *Telemed J*. 1996;2(4):267-271.
 36. Samii A, Ryan-Dykes P, Tsukuda RA, Zink C, Franks R, Nichol WP. Telemedicine for delivery of health care in Parkinson's disease. *J Telemed Telecare*. 2006;12(1):16-18.
 37. Schoffer KL, Patterson V, Read SJ, Henderson RD, Pandian JD, O'Sullivan JD. Guidelines for filming digital camera video clips for the assessment of gait and movement disorders by teleneurology. *J Telemed Telecare*. 2005;11(7):368-371.
 38. Paiva T, Coelho H, Araujo MT, et al. Neurological teleconsultation for general practitioners. *J Telemed Telecare*. 2001;7(3):149-154.
 39. Demaerschalk BM, Hwang HM, Leung G. Cost analysis review of stroke centers, telestroke, and rt-PA. *Am J Manag Care*. 2010;16(7):537-544.
 40. Scott PA, Xu Z, Meurer WJ, et al. Attitudes and beliefs of Michigan emergency physicians toward tissue plasminogen activator use in stroke: baseline survey results from the INcreasing Stroke Treatment through INteractive behavioral Change Tactic (INSTINCT) trial hospitals. *Stroke*. 2010;41(9):2026-2032.
 41. Adeoye O, Jornung R, Khatri P, Kleindorfer D. Recombinant tissue-type plasminogen activator use for ischemic stroke in the United States: A doubling of treatment rates over the course of 5 years. *Stroke*. 2011;42(7):1952-1955.
 42. Kleindorfer D, Xu Y, Moomaw CJ, Khatri P, Adeoye O, Hornung R. US geographic distribution of rt-PA utilization by hospital for acute ischemic stroke. *Stroke*. 2009;40(11):3580-3584.
 43. Demaerschalk BM. Seamless integrated stroke telemedicine systems of care: a potential solution for acute stroke care delivery delays and inefficiencies. *Stroke*. 2011;42(6):1507-1508.
 44. Goldstein LB. Statewide hospital-based stroke services in North Carolina: changes over 10 years. *Stroke*. 2010;41(4):778-783.
 45. Gross H, Hall C, Switzer JA, et al. Using tPA for acute stroke in a rural setting. *Neurology*. 2007;68(22):1957-1958; author reply 8.

46. Gross H, Hall CE, Wang S, et al. Prospective reliability of the STRoKE DOC Wireless/Site Independent Telemedicine System. *Neurology*. 2006;66(3):460.
47. Handschu R, Littmann R, Reulbach U, et al. Telemedicine in emergency evaluation of acute stroke: interrater agreement in remote video examination with a novel multimedia system. *Stroke*. 2003;34(12):2842-2846.
48. Handschu R, Scibor M, Willaczek B, et al. Telemedicine in acute stroke: remote video-examination compared to simple telephone consultation. *J Neurol*. 2008;255(11):1792-1797.
49. Henninger N, Chowdhury N, Fisher M, Moonis M. Use of telemedicine to increase thrombolysis and advance care in acute ischemic stroke. *Cerebrovasc Dis*. 2009;27(suppl 4):9-14.
50. Hess DC, Wang S, Gross H, Nichols FT, Hall CE, Adams RJ. Telestroke: extending stroke expertise into underserved areas. *Lancet Neurol*. 2006;5(3):275-278.
51. Hess DC, Wang S, Hamilton W, Lee S, Pardue C, Waller JL, et al. REACH: clinical feasibility of a rural telestroke network. *Stroke*. 2005;36(9):2018-2020.
52. Choi JY, Porche NA, Albright KC, Khaja AM, Ho VS, Grotta JC. Using telemedicine to facilitate thrombolytic therapy for patients with acute stroke. *Jt Comm J Qual Patient Saf*. 2006;32(4):199-205.
53. Crome O, Bahr M. Editorial comment—Remote evaluation of acute ischemic stroke: a reliable tool to extend tissue plasminogen activator use to community and rural stroke patients? *Stroke*. 2003;34(10):e191-e192.
54. de Bustos EM, Moulin T, Audebert HJ. Barriers, legal issues, limitations and ongoing questions in telemedicine applied to stroke. *Cerebrovasc Dis*. 2009;27(suppl 4):36-39.
55. Moskowitz A, Chan YF, Bruns J, Levine SR. Emergency physician and stroke specialist beliefs and expectations regarding tel-stroke. *Stroke*. 2010;41(4):805-809.
56. LaMonte MP, Bahouth MN, Hu P, et al. Telemedicine for acute stroke: triumphs and pitfalls. *Stroke*. 2003;34(3):725-728.
57. de Bustos EM, Vuillier F, Chavot D, Moulin T. Telemedicine in stroke: organizing a network—rationale and baseline principles. *Cerebrovasc Dis*. 2009;27(suppl 4):1-8.
58. Demaerschalk BM. Telemedicine or telephone consultation in patients with acute stroke. *Curr Neurol Neurosci Rep*. 2011; 11(1):42-51.
59. Demaerschalk BM, Bobrow BJ, Raman R, et al. Stroke team remote evaluation using a digital observation camera in Arizona: the initial mayo clinic experience trial. *Stroke*. 2010;41(6): 1251-1258.
60. Demaerschalk BM, Miley ML, Kiernan TE, et al. Stroke telemedicine. *Mayo Clin Proc*. 2009;84(1):53-64.
61. Anderson ER, Smith B, Ido M, Frankel M. Remote assessment of stroke using the iPhone 4. *J Stroke Cerebrovasc Dis*. 2011. [Epub ahead of print].
62. Lai F. Stroke networks based on robotic telepresence. *J Telemed Telecare*. 2009;15(3):135-136.
63. American Telemedicine Association link to Products and Vendors. <http://atatelemedicinedirectory.com/>.
64. Shafqat S, Kvedar JC, Guanci MM, Chang Y, Schwamm LH. Role for telemedicine in acute stroke. Feasibility and reliability of remote administration of the NIH stroke scale. *Stroke*. 1999; 30(10):2141-2145.
65. Pervez MA, Silva G, Masrur S, et al. Remote supervision of IV-tPA for acute ischemic stroke by telemedicine or telephone before transfer to a regional stroke center is feasible and safe. *Stroke*. 2010;41(1):e18-e24.
66. Levine SR, Gorman M. "Telestroke": the application of telemedicine for stroke. *Stroke*. 1999;30(2):464-469.
67. Levine SR, McConnochie KM. Telemedicine for acute stroke: when virtual is as good as reality. *Neurology*. 2007;69(9): 819-820.
68. Audebert HJ, Kukla C, Clarmann von Claranau S, et al. Telemedicine for safe and extended use of thrombolysis in stroke: the Telemedic Pilot Project for Integrative Stroke Care (TEMPiS) in Bavaria. *Stroke*. 2005;36(2):287-291.
69. Audebert HJ, Schenkel J, Heuschmann PU, Bogdahn U, Haberl RL. Effects of the implementation of a telemedical stroke network: the Telemedic Pilot Project for Integrative Stroke Care (TEMPiS) in Bavaria, Germany. *Lancet Neurol*. 2006;5(9): 742-748.
70. Audebert HJ, Schultes K, Tietz V, et al. Long-term effects of specialized stroke care with telemedicine support in community hospitals on behalf of the Telemedical Project for Integrative Stroke Care (TEMPiS). *Stroke*. 2009;40(3):902-908.
71. Khan K, Shuaib A, Whittaker T, et al. Telestroke in northern alberta: a two year experience with remote hospitals. *Can J Neurol Sci*. 2010;37(6):808-813.
72. LaMonte MP, Cullen J, Gagliano DM, et al. TeleBAT: mobile telemedicine for the Brain Attack Team. *J Stroke Cerebrovasc Dis*. 2000;9(3):128-135.
73. Meyer BC, Lyden PD, Al-Khoury L, et al. Prospective reliability of the STRoKE DOC wireless/site independent telemedicine system. *Neurology*. 2005;64(6):1058-1060.
74. Meyer BC, Raman R, Hemmen T, et al. Efficacy of site-independent telemedicine in the STRoKE DOC trial: a randomised, blinded, prospective study. *Lancet Neurol*. 2008;7(9): 787-795.
75. LaMonte MP, Bahouth MN, Xiao Y, Hu P, Baquet CR, Mackenzie CF. Outcomes from a comprehensive stroke telemedicine program. *Telemed J E Health*. 2008;14(4):339-344.
76. Audebert HJ, Schwamm L. Telestroke: scientific results. *Cerebrovasc Dis*. 2009;27(suppl 4):15-20.
77. Amarenco P, Nadjar M. Telemedicine for improving emergent management of acute cerebrovascular syndromes. *Int J Stroke*. 2007;2(1):47-50.
78. Tatlisumak T, Soinila S, Kaste M. Telestroke networking offers multiple benefits beyond thrombolysis. *Cerebrovasc Dis*. 2009; 27(suppl 4):21-27.
79. Schwab S, Vatankeh B, Kukla C, et al. Long-term outcome after thrombolysis in telemedical stroke care. *Neurology*. 2007; 69(9):898-903.
80. Nelson RE, Saltzman GM, Skalabrin EJ, Demaerschalk BM, Majersik JJ. The cost-effectiveness of telestroke in the treatment of acute ischemic stroke. *Neurology*. 2011;77(17): 1590-1598.

81. Smith EE, Dreyer P, Prvu-Bettger J, et al. Stroke center designation can be achieved by small hospitals: the Massachusetts experience. *Crit Pathw Cardiol*. 2008;7(3):173-177.
82. Audebert HJ, Wimmer ML, Hahn R, et al. Can telemedicine contribute to fulfill WHO Helsingborg Declaration of specialized stroke care? *Cerebrovasc Dis*. 2005;20(5):362-369.
83. Miley ML, Demaerschalk BM, Olmstead NL, et al. The state of emergency stroke resources and care in rural Arizona: a platform for telemedicine. *Telemed J E Health*. 2009;15(7):691-699.
84. Amory CF, Levine SR. Is telemedicine the answer for delivering stroke care to rural areas? *Nat Clin Pract Neurol*. 2007;3(4):192-193.
85. Vatankhah B, Schenkel J, Furst A, Haberl RL, Audebert HJ. Telemedically provided stroke expertise beyond normal working hours. The Telemedical Project for Integrative Stroke Care. *Cerebrovasc Dis*. 2008;25(4):332-337.
86. Walter S, Kostopoulos P, Haass A, et al. Bringing the hospital to the patient: first treatment of stroke patients at the emergency site. *PLoS One*. 2010;5(10):e13758.
87. Schwamm LH, Rosenthal ES, Hirshberg A, et al. Virtual Tele-Stroke support for the emergency department evaluation of acute stroke. *Acad Emerg Med*. 2004;11(11):1193-1197.
88. Wang DZ. Editorial comment—telemedicine: the solution to provide rural stroke coverage and the answer to the shortage of stroke neurologists and radiologists. *Stroke*. 2003;34(12):2957.
89. Wang S, Gross H, Lee SB, et al. Remote evaluation of acute ischemic stroke in rural community hospitals in Georgia. *Stroke*. 2004;35(7):1763-1768.
90. Wiborg A, Widder B. Teleneurology to improve stroke care in rural areas: The Telemedicine in Stroke in Swabia (TESS) Project. *Stroke*. 2003;34(12):2951-2956.
91. Wang S, Lee SB, Pardue C, et al. Remote evaluation of acute ischemic stroke: reliability of National Institutes of Health Stroke Scale via telestroke. *Stroke*. 2003;34(10):e188-e191.
92. Meyer BC, Raman R, Chacon MR, Jensen M, Werner JD. Reliability of site-independent telemedicine when assessed by telemedicine-naïve stroke practitioners. *J Stroke Cerebrovasc Dis*. 2008;17(4):181-186.
93. Rubin M. Teleneurology report card: proof of concept. *Pract Neurol*. 2011;32-34.
94. Patterson V. Teleneurology. *J Telemed Telecare*. 2005;11(2):55-59.
95. Craig J, Patterson V, Russell C, Wootton R. Interactive video-consultation is a feasible method for neurological in-patient assessment. *Eur J Neurol*. 2000;7(6):699-702.
96. Brown SW. Will teleneurology hit the big time? *Lancet Neurol*. 2004;3(9):517-518.
97. Craig J, Chua R, Russell C, Wootton R, Chant D, Patterson V. A cohort study of early neurological consultation by telemedicine on the care of neurological inpatients. *J Neurol Neurosurg Psychiatry*. 2004;75(7):1031-1035.
98. Ganapathy K. Role of telemedicine in neurosciences. *Stud Health Technol Inform*. 2004;104:116-124.
99. Ganapathy K. Telemedicine and neurosciences. *J Clin Neurosci*. 2005;12(8):851-862.
100. Ganapathy K. Telemedicine in neurology. *Neurol India*. 2005;53(2):242; author reply.
101. Garcia E, Guyennet H, Lapayre JC, Moulin T. Adaptive tele-application for remote neurology diagnosis. *Telemed J E Health*. 2005;11(6):692-702.
102. Singh R, Ng WH, Lee KE, Wang E, Ng I, Lee WL. Telemedicine in emergency neurological service provision in Singapore: using technology to overcome limitations. *Telemed J E Health*. 2009;15(6):560-565.
103. Misra UK, Kalita J, Mishra SK, Yadav RK. Telemedicine in neurology: underutilized potential. *Neurol India*. 2005;53(1):27-31.
104. Patterson V, Wootton R. How can teleneurology improve patient care? *Nat Clin Pract Neurol*. 2006;2(7):346-347.
105. Craig J, Chua R, Russell C, Patterson V, Wootton R. The cost-effectiveness of teleneurology consultations for patients admitted to hospitals without neurologists on site. 1: A retrospective comparison of the case-mix and management at two rural hospitals. *J Telemed Telecare*. 2000;6(suppl 1):S46-S49.
106. Patterson V. How best to organise acute hospital services? Realtime teleneurology can help small hospitals. *BMJ*. 2001;323(7324):1306.
107. Patterson V. Teleneurology in Northern Ireland: a success. *J Telemed Telecare*. 2002;8(suppl 3):S3:46-47.
108. Patterson V, Conneally P. Intercontinental telemedicine for acute neurology. *J Telemed Telecare*. 2005;11(6):320-322.
109. Patterson V, Hoque F, Vassallo D, Farquharson Roberts M, Swinfen P, Swinfen R. Store-and-forward teleneurology in developing countries. *J Telemed Telecare*. 2001;7(suppl 1):52-53.
110. Yozbatiran N, Harness ET, Le V, Luu D, Lopes CV, Cramer SC. A tele-assessment system for monitoring treatment effects in subjects with spinal cord injury. *J Telemed Telecare*. 2010;16(3):152-157.
111. Patterson VH, Craig JJ, Wootton R. Effective diagnosis of spinal cord compression using telemedicine. *Br J Neurosurg*. 2000;14(6):552-554.
112. Patterson V, Bingham E. Telemedicine for epilepsy: a useful contribution. *Epilepsia*. 2005;46(5):614-615.
113. Vespa PM, Miller C, Hu X, Nenov V, Buxey F, Martin NA. Intensive care unit robotic telepresence facilitates rapid physician response to unstable patients and decreased cost in neurointensive care. *Surg Neurol*. 2007;67(4):331-337.
114. Vespa PM. Multimodality monitoring and telemonitoring in neurocritical care: from microdialysis to robotic telepresence. *Curr Opin Crit Care*. 2005;11(2):133-138.
115. Patterson V, Craig J, Pang KA, Wootton R. Successful management of unexplained coma by telemedicine. *J Telemed Telecare*. 1999;5(2):134-136.
116. Meeker M, Du R, Bacchetti P, et al. Pupil examination: validity and clinical utility of an automated pupillometer. *J Neurosci Nurs*. 2005;37(1):34-40.
117. Chen JW, Gombart ZJ, Rogers S, Gardiner SK, Cecil S, Bullock RM. Pupillary reactivity as an early indicator of increased intracranial pressure: the introduction of the neurological pupil index. *Surg Neurol Int*. 2011;2:82.

118. Taylor WR, Chen JW, Meltzer H, et al. Quantitative pupillometry, a new technology: normative data and preliminary observations in patients with acute head injury. Technical note. *J Neurosurg*. 2003;98(1):205-213.
119. Panoptic Device used with personal digital assistant (PDA), iPhone and iExamine software to examine the retina by local examiner. iExamine—intuitive medtech <http://www.youtube.com/user/IntuitiveMedTech>.
120. Pascoe DA. A pupil gauge. *Anaesthesia*. 1980;35(10):1021.
121. Bradley WG Jr MR-guided focused ultrasound: a potentially disruptive technology *J Am Coll Radiol*. 2009;6(7):510-513.
122. Scherer K, Bedlack RS, Simel DL. Does this patient have myasthenia gravis? *JAMA*. 2005;293(15):1906-1914.
123. Intouch Health Web site. <http://www.intouchhealth.com/>.
124. Reach On Call Web site. <http://reachcall.com/>.
125. Yousem DM, Beauchamp NJ, Jr. Clinical input into designing a PACS. *J Digit Imaging*. 2000;13(1):19-24.
126. Vassallo DJ, Hoque F, Roberts MF, Patterson V, Swinfen P, Swinfen R. An evaluation of the first year's experience with a low-cost telemedicine link in Bangladesh. *J Telemed Telecare*. 2001;7(3):125-138.
127. Chemak C, Bouhlef MS, Lapayre JC. Neurology diagnostics security and terminal adaptation for PocketNeuro project. *Telemed J E Health*. 2008;14(7):671-678.
128. Busis N. Mobile phones to improve the practice of neurology. *Neurol Clin*. 2010;28(2):395-410.
129. Takao H, Murayama Y, Ishibashi T, Karagiozov KL, et al. A new support system using a mobile device (Smartphone) for diagnostic image display and treatment of stroke. *Stroke*. 2012;43(1):236-239.
130. Weintraub MI. Thrombolysis (tissue plasminogen activator) in stroke: a medicolegal quagmire. *Stroke*. 2006;37(7):1917-1922.
131. Switzer JA, Levine SR, Hess DC. Telestroke 10 years later—'telestroke 2.0'. *Cerebrovasc Dis*. 2009;28(4):323-330.
132. Demaerschalk BM, Kiernan TE, STARR Investigators. Vascular neurology nurse practitioner provision of telemedicine consultations. *Int J Telemed Appl*. 2010;2010.
133. Misra UK, Kalita J, Mishra SK, Yadav RK. Telemedicine for distance education in neurology: preliminary experience in India. *J Telemed Telecare*. 2004;10(6):363-365.
134. About remote evaluation of stroke patients. Patient page. *Neurology*. 2010;74(21):e95-e96.
135. Huston JL, Burton DC. Patient satisfaction with multispecialty interactive teleconsultations. *J Telemed Telecare*. 1997;3(4):205-208.
136. Mikulik R, Alexandrov AV, Ribo M, et al. Telemedicine-guided carotid and transcranial ultrasound: a pilot feasibility study. *Stroke*. 2006;37(1):229-230.
137. Switzer JA, Hall CE, Close B, et al. A telestroke network enhances recruitment into acute stroke clinical trials. *Stroke*. 2010;41(3):566-569.
138. FDA statement of telemedicine devices/regulations. <http://edocket.access.gpo.gov/2011/pdf/2011-3321.pdf>.