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Systematic Review of Telestroke for Post-Stroke Care and Rehabilitation

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Abstract Telemedicine for acute stroke care is supported by a literature base. It remains unclear whether or not the use of telemedicine for other phases of stroke care is beneficial. The authors conducted a systematic review of the published literature on telemedicine for the purposes of providing post-stroke care. Studies were included if the title or abstract expressed use of two-way audio/video communication for post-stroke care. From an initial yield of 1,405 potentially eligible hits, two reviewers ultimately identified 24 unique manuscripts to undergo *f*unctionality, *a*pplication, *t*echnology, and *e*valuative (F.A.T.E.) scoring. Each article was classified using a scoring rubric to assess the functionality, application, technology, and evaluative stage. It was found that most post-stroke telemedicine studies evaluated rehabilitation of adults. All primary data manuscripts were small and preliminary in scope and evaluative phase, and median F.A.T.E. score for primary data was 2. The use of telemedicine for post-stroke care is nascent and is primarily focused on post-stroke rehabilitation.

Keywords Telestroke · Telemedicine · Stroke · Rehabilitation · Systematic review · Telecommunications · Remote consultation

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Introduction

Cerebrovascular disease, including acute ischemic stroke, remains a major public health problem in the United States [1] and throughout the world [2]. There has been a concerted effort to apply evidence-based practices to stroke care in order to improve primary and secondary prevention, as well as post-stroke outcomes. One facet of this effort includes the development and accreditation of primary and comprehensive stroke centers, which have been demonstrated to improve stroke care [3]. During post-stroke care, venous thromboembolism prophylaxis, initiation of antithrombotic and statin therapies, and a rehabilitation assessment are among the myriad of factors accepted as best practice after acute stroke. Geography contributes to a disparity in stroke care, however, as most stroke centers are based in large, urban academic medical centers. It is estimated that upwards of 40 % of the United States population resides outside the reasonable clinical reach of a primary stroke center. Furthermore, there remains a shortage of vascular neurologists, who are otherwise best equipped to provide desired outcomes [4–6], to meet the heavy demands of incident stroke.

In an attempt to combat this rural to urban disparity and expand the availability of best stroke practices, Levine and Gorman proposed the development of real-time two-way audio-visual telemedical outreach for acute stroke evaluation and management, which they called “telestroke” [7]. Since then, the practice of telestroke has been found to have a high interrater agreement with a beside assessment of National Institutes of Health Stroke Scale (NIHSS) score [8], to enhance correct thrombolysis decision making as compared to telephone-only consultation [9, 10•, 11], and to be cost-effective from hospital and societal perspectives [12••, 13•]. In light of these findings and the perception of benefit by stroke providers and patients, there has been a rapid expansion of telestroke networks both in the United States [14] and internationally [15].

The term “telestroke” has been defined as “live, audio-video telecommunication applied to care of acute stroke”

[15]. This definition, however, fails to recognize the use of this means of communication with patients by those who provide their services in the aftermath of an acute stroke. There are numerous, well written narrative reviews [15–18] and fairly recent systematic reviews [19, 20] of telestroke for acute stroke diagnosis and management. The authors suggest that the literature base, however, lacks an encompassing but easily and rapidly digestible "dashboard view" of the state of the art for post-stroke care. The aim of this manuscript is to present a rigorous, comprehensive, up-to-date systematic review of all published studies involving telemedicine for post-stroke evaluation and management within the framework of a rubric for assessing the telemedical literature, the *f*unctionality, *a*pplication, *t*echnology, and *e*valuative (F.A.T.E.) template [21]. The authors contend that the multidimensionality of the rubric, which scores studies based on *f*unctionality, *a*pplication, *t*echnology, and stage of *e*valuation, allows for a "bird's eye" view of an individual study and indeed a category of telemedical literature. The F.A.T.E. template was introduced with the publication of the systematic review methodology employed by the authors [21]. Within that publication, it was suggested that the template might serve to qualify either an individual telemedical study or category review as relatively nascent or mature, based on the score. The score depends primarily on elements of functionality and evaluation phase; thus, one can infer greater functionality and/or methodological rigor of a study or collection thereof from higher scores.

Methods

Systematic Review

Ovid MEDLINE was searched from 1996 to July 2012 Week 3 to identify relevant studies for review. A search strategy utilizing MeSH (Medical Subject Headings), textwords, and telemedicine journal titles was conducted to create one large set of terms for telemedicine. This basic set included the MeSH terms Telemedicine, Telecommunications, and Remote Consultation. Textwords included telestrokologist, telestroke, teleneurology, telemedicine, telecare, telehealth, telerehabilitation, telediagnosis, telemonitor, teletherapy, telehomecare, teleconsultation; remote consultation, remote supervision, remote monitoring, remote evaluation, remote interpretation; e-health, e-therapy, e-diagnosis, e-intervention; internet-based, televideo, video-teleconference, hq-vtc, ICT, televideo, video consultation, real time video communication, two-way audio visual, two-way video communication, two-way television, videoconference, video examination, virtual reality, or Smartphone. All textwords were truncated for variant word endings and plurals as necessary.

Journals included were Telemedicine & Telehealth Networks, Telemedicine & Virtual Reality, Telemedicine Journal, Telemedicine & eHealth, Telemedicine Today, and Journal of Telemedicine & Telecare. All MeSH, textwords and journals were combined using the Boolean operator "OR". A second set was created with the exploded MeSH terms Stroke and Cerebrovascular Disorders joined with the textword stroke using the Boolean "OR". The two major sets were combined with the Boolean "AND". The resulting set was limited to humans and the publication types "comment" and "letter" were removed. This basic search was altered as needed when searching additional databases including EMBASE, PsychINFO, CINAHL, PubMed and Cochrane.

The initial search yielded 1,405 abstracts that were independently reviewed by authors MNR and BMD (see Fig. 1). Studies that met the predetermined inclusion criterion were selected for further appraisal. The inclusion criterion was that a study must offer an approach to post-stroke evaluation and management using two-way audio-visual communication. There was excellent agreement in the abstract screening process ($\kappa=0.98$) and consensus to include 54 of the search hits. Of note, there were numerous "repeat hits," where different facets of the search strategy yielded the same study; thus, there were only 42 unique studies requested for full-text review. Author MNR reviewed each of those studies and, after exclusions based on the criterion, duplicate retrieval, and non-English language, 24 unique studies were included in the review and studied in detail.

Each of the 24 studies was reviewed using the F.A.T.E. template. The numerical score was derived from elements of functionality and the phase of evaluation as previously described [21]. A study could be assigned a total of four possible points for functionality relating to consultation, diagnosis, monitoring, or mentoring, garnering one point for each (e.g., the F score). Points were also given based on the phase of evaluation, with the number of points equivalent to the phase, for a potential total of 5 points from that category (e.g., the E score). These two were added to designate the F.A.T.E. score of an individual article. Technological aspects of the equipment used in individual studies, including (a)synchronicity, videoconference capability, use of telemetric monitoring, wireless capability, minimum bandwidth used, and display resolution were recorded. Simultaneous review of this manuscript with the open-access publication of our study methods and further discussion of the F.A.T.E. template is encouraged [21]. The recommendations of the PRISMA statement were followed [22].

Results

See Table 1 for a detailed overview of the number of instances a particular facet of the F.A.T.E. template was scored among the 24 post-stroke telemedicine publications reviewed. Within the subcategories of functionality, application, and

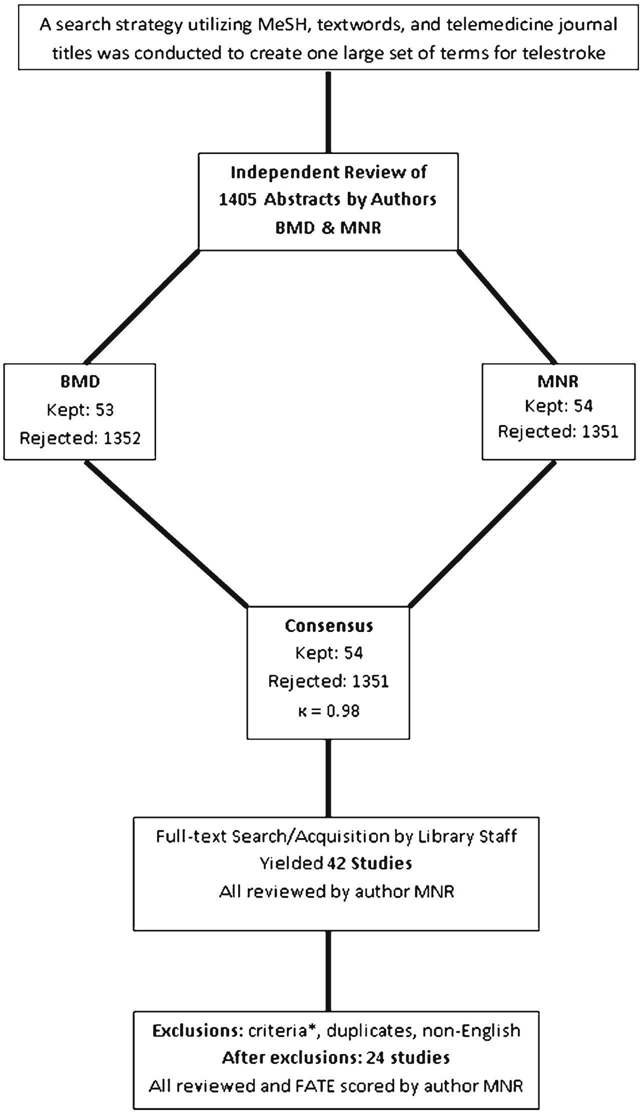

Fig. 1 A flowchart of the systematic review methodology *To be included, a study must offer an approach to post-stroke evaluation and management using two-way audio-visual communication

technology, there existed the possibility of numerous, non-mutually-exclusive instances, as well as absence of detailed information in study methods, which is why the numbers do not add up to 24.

Functionality

The majority of publications that evaluated the functionality of a telemedicine system studied its use for post-stroke consultation (n=13). Only three publications studied its use for post-stroke telemetric monitoring, and six involved mentoring of patients post-stroke and/or stroke providers.

Application

Application of post-stroke telemedicine was subcategorized as depicted in Table 1. Most publications were directed at studies of consultation for adults (n=17) requiring post-stroke rehabilitation (n=15), often times in the home setting (n=8). Of note, most of the studies did not mention a specific age range for inclusion or exclusion; however, by inference from the tremendously disproportionate burden of ischemic stroke in adults as compared to children, virtually all studies were of adults. There were no studies that focused on post-stroke telemedicine for pediatric consultation. There were also no studies of post-stroke telemedicine use in an Intensive Care Unit (ICU) setting. There were several manuscripts (n=4) that compared face-to-face and telemedicine-mediated educational sessions for patients with stroke and non-expert stroke providers. A single study involved the use of telemedicine to make neurosonological diagnosis in the (post-acute evaluation) emergency department and clinic setting.

Technology

Post-stroke telemedicine technology was subcategorized as depicted in Table 1. Most studies applied synchronous (n=

Table 1 Overview of telestroke study characteristics by F.A.T.E. template

Functionality		Application		Technology		Evaluation	
Consultation	13	Adults	17	Synchronous	16	I	16
Diagnosis	1	Children	0	Asynchronous	0	II	0
Monitoring	3	ED	1	Separate A/V devices	2	III	0
Mentoring	6	ICU	0	Videoconferencing	12	IV	0
		Med/Surg	0	Telemetry	2	V	0
		Pre-hospital	0	Wireless	2	N/A	8
		Home	8	Wired	8		
		rehabilitation	15	Bandwidth range, kbps	384–10,000		
		training	4				

ED—emergency department; *ICU*—intensive care unit; *Med/Surg*—medical/surgical ward; *A/V*—audio/visual; *kbps*—kilobits per second; *N/A*—not applicable

16) videoconferencing technology (e.g., integrated audio and video, $n=12$). None made use of the various means of asynchronous, "store-and-forward" communication for post-stroke telemedicine. Only two studies of synchronized audio-visual communication involved non-integrated audio and visual devices (e.g., live video stream and cellular phone for audio). Two studies incorporated telemetric monitoring of vital signs into its data set. When mentioned, more studies incorporated a hard-wired setup ($n=8$) than a wireless system ($n=2$); however, most studies did not mention this particular technological feature and there was also often a hybrid system involving some wireless and some wired components of the telestroke network. Bandwidth was infrequently mentioned and never studied, with a range of 384 to 10,000 kilobits per second (kbps) and a mode of 10,000 kbps. Image resolution was mentioned in only a single study, and was quite poor by modern standards (e.g., 128×96 pixels).

Evaluation

Of the 16 studies that displayed a distinct phase of evaluation, all represented small pilots and were exploratory in nature, which represented evaluative phase I. There were no randomized controlled trials, economic analyses or post-implementation studies. Of note, one-third of the manuscripts ($n=8$) had a scope outside of the F.A.T.E. range of evaluative phase, and were mostly review articles. These reviews addressed the same primary data scrutinized in this systematic review.

Focus

The inferred focus(es) of post-stroke telestroke literature was tracked. Nearly all manuscripts were written in the traditional format of medical journals and were directed at providers ($n=23$). A fair number of studies incorporate data and text that were intended for policy makers ($n=14$). There were only a limited number of articles that were designed for a patient audience ($n=3$) or clearly aimed at payers ($n=5$).

F.A.T.E. Scoring

As noted in Table 1, the most common F score was 1, for consultative functionality. All 16 primary data studies garnered an E score of 1.

F.A.T.E. scores of each of the 24 evaluated articles were recorded and then compiled in order to ascertain a post-stroke telemedicine category F.A.T.E. score. The average F.A.T.E score was calculated to be 1.58, with a median of 2 and a mode of 2. When removing the studies that scored a F.A.T.E. of 0, the average F.A.T.E. score was 2.38 with a median of 2. The citations with their respective F.A.T.E. score are detailed in Table 2.

Highlight Articles

Many of the manuscripts included in this review detail pilots of home telerehabilitation systems for patients who have experienced a stroke. These surely represent an important step in advancing the field and a sturdy foundation for future study. In this section, we highlight some of the studies that evaluated videoconferencing infrastructure for other, non-physiatric elements of post-stroke care.

Vascular imaging represents an important facet of post-stroke care. An interesting pilot study conducted by Mikulik et al. compared logistics of performing a transcranial doppler (TCD) and carotid duplex (CD) examination by telemedical guidance of a novice *versus* an in-person examination by an experienced sonographer [26]. They performed telemedical and in-person studies in each of eight patients. There was reasonable agreement in the findings, particularly in the seven patients with sonographically normal carotid and intracranial vasculature. There was some discrepancy between modalities in interpretation of TCD parameters of the middle cerebral arteries in the lone patient who had abnormal findings, but the major underlying abnormality (*e.g.*, carotid occlusion) was correctly diagnosed by both the in-person and telemedically guided sonographers. There was also a significant difference in time-to-completion between the in-person and telemedicine studies, with the telemedicine studies taking two-to-three times longer than in-person evaluations, but the median times were still within reasonable outpatient vascular laboratory time allotment. Their conclusion was that telemedical guidance of TCD and CD studies by an experienced sonographer was feasible for non-urgent studies and had good agreement with in-person studies in patients with normal vasculature.

The rural–urban disparity in stroke care extends beyond the consideration of t-PA administration. Schwieckert et al. conducted a pilot of providing stroke awareness education to a rural Appalachian community via videoconferencing as compared to standard, in-person counseling [28]. There were 11 participants, six in the telemedicine group and five who received in-person counseling. The groups were equally matched in previous telehealth exposure and level of education. All participants were elderly (age range, 64–76 years) and lived in rural Virginia. Knowledge of stroke signs and risk factors, likelihood of changing habits, and satisfaction with method of counseling were measured in all participants. There were significant changes pre-counseling and post-counseling in all participants, all to a similar degree. The authors concluded that videoconferencing was a feasible and satisfying means of providing stroke education to the rural elderly.

Beyond educating the community at large, stroke education must be conferred effectively to medical professionals. Carter et al. described their experience with a videoconference and

Table 2 Post-stroke telestroke studies and their F.A.T.E. score

Citation	FATE Score
Gregory, et al. [25]	0
Mikulik, et al. [26]	4
Perry, et al. [27]	0
Schweickert, et al. [28]	2
Waters [29]	0
Piron, et al. [30]	2
Maeno et al. [31]	2
Huijgen, et al. [32]	2
Lai, et al. [33]	2
Tran, et al. [34]	0
Carter, et al. [35]	2
Durfee, et al. [36]	3
Brennan, et al. [37]	2
Joubert, et al. [38]	0
Johansson, et al. [39]	0
Durfee, et al. [40]	2
Broeren, et al. [41].	3
Yu [42]	0
Marziali, et al. [43]	3
Palsbo, et al. [44]	2
Buckley, et al. [45]	2
Stein, et al. [46]	0
*Huijbregts, et al. 2010 International Stroke Conference # P404/Taylor, et al. [47]	3
Brennan, et al. [48]	2

*These citations involve the same study and authors, one representing the manuscript and the other the meeting at which it was presented

web-based stroke nursing education program [35]. They surveyed 96 nurses on their confidence in using videoconference and web-based educational technologies, perception of competence to provide care to stroke patients, and satisfaction with the education program. In brief, all participants found the program satisfying, and there was a significant increase in the general perception of competence between pre-program and post-program surveys. The authors concluded that their program was an effective educational tool for stroke nursing providers that has the additional benefit of flexibility for the dyanmic lifestyle of a nurse.

Another aspect of post-stroke care for patients with aphasia is a consultation with a speech pathologist. A pilot study by Brennan et al. sought to determine if telemedicine is an effective means of providing this service [48]. They studied 40 patients who each underwent in-person and telemedical observation while performing the Story Retelling Procedure. The goal was to identify any difference in performance between the experimental (e.g., telemedical) or control (e.g., in-person) settings and, if any were found, associate them with any demographics such as age, gender, or experience with technology. No significant differences were found in performance between the two settings, and no demographic features predicted particularly good or poor performances in any setting. The telemedical method was also highly satisfactory to participants. The authors concluded that videoconferencing has potential in speech and language pathology, but requires more investigation.

Discussion

This review represents the first, rigorous systematic review of the post-stroke telemedicine literature. The aim of this review was to provide an easily digestible, practical overview of post-stroke telemedicine such that current and future telestroke providers and investigators can learn from what has been done, and how it was done, in order to be best equipped to contribute to future research and practice.

Telestroke is considered mainstream. As has been published elsewhere [20], telestroke has a robust literature base of feasibility studies and an encouraging trend toward use in the pre-hospital setting to enhance time to thrombolysis in acute stroke. It was also pointed out that there are only three randomized controlled trials and four cost analyses of telestroke to date, as well as a plurality of narrative reviews. With that in mind, the authors suggested that the field (and with hope, patients) would benefit from attention to large scale randomized controlled trials and further health economic analyses.

The F.A.T.E. category score for post-stroke telemedicine is indicative of the nascency of the field. While there were a few studies that explored multi-dimentional functionality (e.g., consultation, monitoring and mentoring in the same pilot), no manuscript was beyond the initial evaluative phase. The authors previously suggested that the F 2-E 2/F.A.T.E. 4 score serves as a reasonable "line" for dichotomization between more or less sophisticated telemedical studies [20]. This is based on a score of F 2-E 2 representing the minimum score for the use of telemedicine for diagnosis and consultation in a post-pilot study phase. Most of the studies in post-stroke telemedicine concerned the use of a robotic telerehabilitation device with integrated two-way AV in a small number of patients who recently suffered stroke in either a clinic or home setting. Of note, there were no randomized controlled trials or cost-analyses; larger feasibility trials may be warranted prior to these studies of greater methodological rigor, but high-quality trial and cost-benefit data are needed before widespread implementation.

It is worth noting that the post-stroke telemedicine literature has a relatively large number of narrative reviews. This might be the expected result in a relatively mature field and as the practice grows in utilization and popularity, but was a surprising finding amidst so few manuscripts. A possible alternative explanation for one third of all manuscripts in the field coming in the form of a review might be the perceived importance of early dissemination of the data and opinions of leaders in the field. In light of the substantial upfront costs of a telestroke system [23, 24], it is only reasonable that payers and administrators would require equally substantial evidence that might encourage them to make such an expenditure. Along those lines, the use of high-priced technology to expand the reach of specialty services to patients in a time of great need makes for a compelling argument, possibly enhancing "buy-in" from readership, be they patients, providers, administrators or payers.

More than a decade since its published conceptualization, there is now a robust and growing literature base that supports the use of telestroke in mainstream clinical acute stroke practice. The same cannot be said for the other phases of stroke care, which are still in their infancy. It is noteworthy that telemedicine publications for post-stroke applications represent approximately 6 % of all published articles on telemedicine applied to the broad field of clinical neurological sciences and all of its subspecialties, whereas acute stroke telemedical studies account for approximately 40 % [21].

The trajectory of post-stroke telemedicine research has yet to be firmly established. It seems that physiatrists have published most of the primary data to date, but rehabilitation, although vitally important for stroke victims, is not the only element of post-stroke care that might lend itself to tele-presence. Other potential elements of post-stroke care which may be improved in neurologically underserved communities may include deep venous thrombosis prophylaxis, swallowing assessments, diagnostic study ordering/acquisition/interpretation/result synthesis, determination of stroke mechanism and etiology, antithrombotic administration, anticoagulation administration for patients with atrial fibrillation, cholesterol reducing medication and antihypertensive therapy administration, management of common post-stroke complications, multidisciplinary team post-stroke care, triage for referral to medical and surgical subspecialties, patient and family education, palliative care, discharge planning, reintegration of patient into the community, prevention of unnecessary readmissions, compliance with treatment recommendations, and participation in stroke prevention research. The use of telestroke videoconferencing infrastructure for education of medical trainees and the medical community at large about acute and post-stroke evaluation and management, although reasonable on its face, remains largely unstudied. Perhaps most importantly, there is a relative dearth of randomized controlled trials and cost analyses, which might otherwise serve to buttress the practice and dissolve barriers to the implementation of post-stroke telemedicine. In addition, the authors suggest, based on critical review of all published telestroke literature, that telestroke research priority be assigned, in no particular order, to demonstration of equivalence in post-stroke care delivery, cost analysis, financial sustainability (through cost reduction and reimbursement models), and use as a tool for education of stroke providers, as well as stroke prevention in the community.

Conclusion

The published use of telestroke infrastructure for post-stroke care is in its nascency. The use thereof has not been extensively studied, and no randomized trials or cost analyses exist. With hope, the benefits of telestroke for acute stroke evaluation and management can be realized in post-stroke care as well.

Conflict of Interest Mark N Rubin declares that he has no conflict of interest.

Kay E Wellik declares that she has no conflict of interest.

Dwight D Channer declares that he has no conflict of interest.

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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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- •• Of major importance

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