Role of telemedicine in the management of acute ischemic stroke

Jonathan Birns*[1], Angela Roots[1] & Ajay Bhalla[1]

Practice Points

- Telemedicine allows a stroke physician to provide remote specialist assessment of patients with real-time clinical evaluation.
- Telemedicine facilitates assessment of stroke patients within minutes of arrival to hospital.
- Telemedicine is feasible and acceptable to both patients and clinicians.
- Telemedicine-delivered stroke care is effective within a 'hub and spoke' model in a geographically organized network.
- Correct treatment decisions, with reduced delay in diagnosis, are made more often with telemedicine than with telephone consultation.
- Telemedicine support for stroke patients reduces death and dependency.

SUMMARY Inequalities for care of stroke patients have been demonstrated between different locations and at different times of the week. In order to overcome the inequity of access to specialist stroke care, telemedicine systems that have harnessed computer-based technology have been developed to provide remote specialist assessment of patients with real-time clinical evaluation. An electronic database search was performed of MEDLINE, EMBASE and the Cochrane Library, and extensive manual searching of articles was conducted to identify studies investigating the use of telemedicine in managing acute ischemic stroke. A total of 31 observational and three randomized controlled studies involving 18,690 patients met inclusion criteria. Telemedicine was demonstrated to be safe, effective, feasible and acceptable for managing acute ischemic stroke. It was shown to reduce geographical differences, and increase diagnostic accuracy and uptake of thrombolytic treatment.

[1]Department of Ageing & Health, 9th Floor, North Wing, St Thomas' Hospital, London SE1 7EH, UK
*Author for correspondence: Tel.: +44 207 188 2515; Fax: +44 207 928 2339; jonathan.birns@gstt.nhs.uk

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The national challenge for stroke services is to deliver evidence-based interventions in a timely fashion [101]. Key components of this strategy include the use of fast-track systems with stroke-specific assessment tools to evaluate patients rapidly and the delivery of thrombolytic treatment for patients with acute ischemic stroke. While these processes have been shown to be effective, inequalities for care of stroke patients have been demonstrated between different locations and at different times of the week [102]. Traditionally, stroke specialist care has only been available during 'working hours' in a minority of hospitals, with expertise unavailable at some urban and most rural centers, and in community settings [1,102]. Furthermore, while the benefit of thrombolysis for acute ischemic stroke has been shown to be time-dependent [2], studies have suggested that up to 40% of patients do not arrive at the hospital early enough to be treated and that only 2–5% of patients actually receive it [3]. In order to overcome this gap in availability of and access to stroke specialist treatment, Levine *et al.* developed the concept of telemedicine for stroke ('telestroke') to use state-of-the-art video telecommunications to maximize the number of patients given effective stroke treatment irrelevant to where and when they presented [4]. They proposed that telestroke could facilitate remote stroke specialist assessment within minutes of attempted contact and suggested that paradigms be developed to provide 'around-the-clock' specialist clinico-radiologic evaluation of stroke patients in all settings.

Over the last decade, computer-based technology has been harnessed to transform a concept into reality with a variety of service models providing audiovisual interaction between patient and stroke clinician across a wide geographical coverage. Most systems feature a high-resolution camera remotely controlled by the stroke specialist with a microphone, speaker and screen for the patient to view the stroke specialist, usually linked via internet-based connections to the stroke specialist's computer. Brain imaging transmission is generally via a picture and archiving communication system. Privacy and security of the system may be maintained by secure socket layer conditional access, data encryption and intruder alerts. A number of validation studies, using an array of technologies, have demonstrated the NIH Stroke Scale to be a swift, accurate, reproducible and reliable remote clinical instrument for acute stroke teleconsultations, and teleradiological assessment of brain imaging has also been shown to be accurate and reliable [5–11].

In this article, we investigate the use of telemedicine in managing acute ischemic stroke by undertaking a systematic review of studies that evaluated telemedicine for stroke both retrospectively and prospectively and that compared stroke management before and after the implementation of telemedicine, by telemedicine versus telephone, and by landline versus mobile telemedicine.

Methods

In October 2012, an electronic database search was performed of MEDLINE, EMBASE and the Cochrane Library using the following MeSH and keywords: 'ischemic', 'stroke', 'telemedicine', 'telestroke' and 'thrombolysis'. The resultant information was supplemented by extensive manual searching of references. Articles lacking numerical data or without an available English translation were excluded. Articles were evaluated against predefined criteria for eligibility and relevance that incorporated the following study characteristics: stroke patient participants, telemedicine-based interventions, comparisons, outcomes and follow-up if pertinent. Inclusion of articles was based on agreement between two independent reviewers (A Bhalla and J Birns) using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement checklist [12]. Included studies were assessed for methodology in terms of cross-sectional, longitudinal or randomized-controlled design with each type being considered separately.

Results

This systematic review identified 34 studies, of varying methodology, that investigated the role of telemedicine in the management of acute ischemic stroke. All articles met the predefined eligibility criteria allowing inclusion in the analysis. Of the 34 studies, two undertook additional patient follow-up analyses on which we also report.

■ Observational studies

A total of 31 observational studies of telemedicine for 18,314 patients presenting with acute stroke have been published and these are summarized in **Tables 1–6**. These have all been undertaken since 2003 and are a mixture of retrospective and

Table 1. Retrospective studies evaluating telemedicine for patients presenting with acute stroke.

Study (year); n	Subjects and study design	Results	Conclusions	Ref.
LaMonte *et al.* (2003); n = 50	Retrospective analysis of telemedicine and telephone consultation for 50 patients presenting to a rural hospital linked via a digital network line to a regional stroke center	Of the 50 consultations, 23 were attempted through telemedicine linkage, and 27 were by telephone conversation; of the 23 telemedicine consultations, two were aborted because of technical difficulties; five patients (24%) received thrombolysis after telemedicine consultation compared with one (4%) evaluated by telephone; no patients experienced complications	Telemedicine consultation provided remote treatment options not previously available; thrombolysis by telemedicine was feasible, safe and tolerated well	[13]
Schwamm *et al.* (2004); n = 24	Retrospective analysis of two-way videoconferencing for the emergency assessment of 24 patients	Six patients (25%) received thrombolysis with a mean door-to-needle time of 106 min (SD: 22 min)	Telemedicine can support emergency department-based evaluation of acute stroke and may facilitate thrombolysis delivery	[14]
Vatankhah *et al.* (2008); n = 8326	Retrospective analysis of 10,239 teleconsultations undertaken in 8326 patients presenting to one of 12 community hospitals connected to two stroke centers via a digital network including a two-way video conference system and CT/MRI image transfer with high-speed data transmission	62% of teleconsultations were requested out of hours; 8.5% of patients received thrombolysis; 16% of teleconsultations yielded nonstroke diagnoses	The majority of teleconsultations were requested beyond normal working times and a significant proportion had an immediate impact on clinical decisions	[15]
Khan *et al.* (2010); n = 210	Retrospective analysis of two-way video link telemedicine and telephone consultation for 210 patients presenting to seven ‘spoke’ hospitals linked to a regional stroke center	34 patients (16%) received thrombolysis after telemedicine consultation compared with ten (5%) evaluated by telephone; five patients experienced intracranial hemorrhage after thrombolysis, of which two were symptomatic; over 2 years, transfer of acute stroke patients from ‘spoke’ hospitals to the regional center decreased by 92.5%	Patients with acute ischemic stroke can be successfully treated by videoconferencing or telephone consultation	[16]
Pedragosa *et al.* (2011); n = 133	Retrospective analysis of telemedicine for 133 patients presenting to a community hospital linked to a regional stroke center	46 patients (35%) received thrombolysis with mean door-to-needle time of 53 min (SD: 38 min); four patients received intra-arterial treatment after transfer to the regional center; four patients experienced intracranial hemorrhage after thrombolysis, of which two were symptomatic	Telestroke allows specialized attention for acute stroke in a community hospital	[17]
Adams *et al.* (2012); n = 1085	Retrospective analysis of telemedicine for 1085 patients presenting to 15 ‘spoke’ hospitals linked to a regional stroke center	231 patients (21%) received thrombolysis with mean door-to-needle time of 98 min (SD: 40 min); 42 patients received intra-arterial treatment after transfer to the regional center	Whilst thrombolysis was facilitated by telemedicine, door-to-needle times fell short of the NIHSS guideline of 60 min	[18]
Ang *et al.* (2012); n = 18	Retrospective analysis of telemedicine for 18 patients who received thrombolysis for acute ischemic stroke	Mean door-to-needle time was 93 min and onset to treatment time was 155 min; door-to-needle time was shorter for patients presenting by ambulance, during office hours and to senior doctors	Telemedicine enables 24-h emergency thrombolysis	[19]

CT: Computed tomography; NIHSS: NIH Stroke Scale; SD: Standard deviation.

prospective evaluation studies of telemedicine, and comparative studies of acute stroke management before and after the implementation of telemedicine, by telemedicine versus telephone and by landline versus mobile telemedicine. Whilst different studies used different outcome measures, 27 of the 31 studies focused on the proportions of acute ischemic stroke patients

Table 2. Prospective studies evaluating telemedicine for patients presenting with acute stroke.

Study (year); n	Subjects and study design	Results	Conclusions	Ref.
Wiborg and Widder (2003); n = 154	Prospective evaluation of 154 patients presenting to seven rural hospitals connected to a stroke center via a video conference link for telemedicine consultation	17 patients (11%) suffered a transient ischemic attack and 40 patients (26%) had a nonstroke diagnosis; mean duration of teleconsultation was 15 min; user and patient satisfaction was good in all cases	Remote telemedicine consultation was feasible	[20]
Wang *et al.* (2004); n = 75	Prospective evaluation of 75 patients presenting to five rural hospitals connected to a stroke center by a broadband-connected workstation	12 of 75 patients (16%) received thrombolysis without complication. Mean onset to door time was 70.9 min (SD: 70.8 min), mean door to consultation time was 45.1 min (SD: 39.8 min), mean door to NIHSS completion was 62.9 min (SD: 50.8 min) and mean OTT time was 135.3 min (SD: 51.5 min)	Telemedicine consultation provided remote treatment options not previously available	[21]
Hess *et al.* (2005); n = 194	Prospective evaluation of 194 patients presenting to eight rural hospitals connected to a stroke center by a broadband-connected workstation	30 of 194 patients (15%) received thrombolysis without complication. The mean OTT time was 122 min; the OTT time dropped from 143 min in the first ten patients treated to 111 min in the last 20 patients	Telemedicine permits the rapid and safe use of thrombolysis in rural community hospitals. Over time, the system became more efficient	[22]
Audebert *et al.* (2005); n = 356	Prospective evaluation of telemedicine assessment of 356 patients presenting to 12 local hospitals connected to two stroke centers via a digital network including a two-way video conference system and CT/MRI image transfer with high-speed data transmission	106 patients (30%) received thrombolysis with symptomatic hemorrhage in 8.5% of patients and an in-hospital mortality of 10.4%; mean duration of teleconsultation was 16 min; mean onset to door time was 65 min (SD: 25 min), mean door-to-needle time was 76 min (SD: 24 min) and mean OTT time was 141 min (SD: 27 min)	Thrombolysis administered by teleconsultation exhibited similar complication rates to those reported in the National Institute of Neurological Disorders and Stroke trial	[23]
Waite *et al.* (2006); n = 88	Prospective analysis of telemedicine service for 88 patients presenting to one of two community hospitals linked to six neurologists from four campuses of two academic centers	27 patients (30%) received thrombolysis with no hemorrhage	Remote telemedicine consultation was feasible	[24]
Sairanen *et al.* (2011); n = 106	Prospective analysis of telemedicine service for 106 patients presenting to one of five community hospitals linked to a regional stroke center	61 patients (58%) received thrombolysis with symptomatic hemorrhage in 6.7% of patients; median OTT time was 120 min; median consultation time was 25 min for patients thrombolysed and 15 min for patients not thrombolysed	A high percentage of teleconsultations led to thrombolysis	[25]

CT: Computed tomography; OTT: Onset to treatment; NIHSS: NIH Stroke Scale; SD: Standard deviation.

receiving thrombolysis and the process times for delivering this treatment.

Both retrospective and prospective studies demonstrated that remote consultation and delivery of thrombolysis by telemedicine was feasible, acceptable and without additional risk to the patient **(Tables 1 & 2)** [13–25]. They also showed that telemedicine afforded the opportunity to deliver acute stroke treatment not previously available due to constraints of working hours or lack of availability of specialist personnel. This was borne out by studies that compared acute stroke management before and after the implementation of telemedicine systems **(Table 3)** [26–28]. Subsequent studies evaluated the potential benefits of telestroke compared with on-site care and further demonstrated the safety of remote stroke management in addition to improvements in stroke management within 'hub and spoke' networks **(Table 4)** [29–40]. **Tables 5 & 6** provide information from recent studies suggesting that telemedicine may be superior to telephone stroke consultation and that mobile telemedicine, compared with landline telemedicine, may be a

Table 3. Studies comparing acute stroke management before and after implementation of telemedicine.

Study (year); n	Subjects and study design	Results	Conclusions	Ref.
Choi *et al.* (2006); n = 655	Comparison of management of 327 patients before and 328 patients after implementation of videoteleconferencing in two community hospitals	3.5% increase (from 0.8 to 4.3%) in the number of patients receiving thrombolysis after implementation of telemedicine with no hemorrhage	Telemedicine facilitated thrombolytic therapy for acute stroke patients	[26]
Pedragosa *et al.* (2009); n = 399	Prospective comparison of management of 201 patients before and 198 patients after implementation of telestroke system between one community hospital and one stroke center using internet access	The telestroke system was used for 38% of cases with an increase in the number of patients evaluated by a specialized neurologist (17 vs 38%; $p < 0.001$) and number of thrombolytic treatments (4.5 vs 9.6%; $p = 0.07$) and a decrease in mean OTT time (210 min [SD: 43 min] vs 162 min [SD: 84 min]; $p = 0.05$)	Telemedicine improved the quality of care administered to acute stroke patients admitted to a community hospital	[27]
Dharmasaroja *et al.* (2010); n = 576	Comparison of management of 170 patients before and 406 patients after implementation of telemedicine system involving 25 ‘spoke’ hospitals connected to one ‘hub’ hospital using internet access	21% increase (from 8 to 27%) in number of patients receiving thrombolysis after implementation of telemedicine network. Walk-in patients had shorter OTT time compared with telemedicine-referred patients (130 vs 170 min; $p < 0.01$) but with no significant difference in favorable outcome (48 vs 42%; $p = 0.54$) or hemorrhage (3 vs 2%; $p = 0.64$)	Implementation of telemedicine markedly increased thrombolysis administration without compromising favorable and safety outcomes	[28]

OTT: Onset to treatment; SD: Standard deviation.

feasible option [41–43]. A significant proportion of the data contributing to the aforementioned findings originates from the TEMPiS study involving two comprehensive stroke centers in Munich-Harlaching and Regensburg in Germany, providing training and education and 24-h telemedical support to 12 regional hospitals [15,23,30,31,43].

Randomized controlled studies

Three randomized controlled trials of telemedicine for acute stroke have been published, the first two of which used hub and spoke models [3,44,45]. In the STRokE DOC trial, over a 3-year period, 222 patients presenting with acute stroke were randomly assigned to telemedicine or telephone consultation to assess their suitability for treatment with thrombolysis. Correct treatment decisions were made more often in the telemedicine group than in the telephone group (108 [98%] vs 91 [82%], odds ratio [OR]: 10.9; 95% CI: 2.7–44.6; $p = 0.0009$). There was also a nonsignificant trend toward increased use of thrombolysis in the telemedicine group compared with the telephone group (28 vs 23%; $p = 0.43$). There was no significant difference in 90-day functional outcome, mortality or rate of intracerebral hemorrhage after treatment with thrombolysis between the two arms of the trial [44]. More recently, in the STRokE DOC Arizona trial, over an 11-month period, Demaerschalk *et al.* randomized 54 acute stroke patients to telemedicine or telephone consultation to assess their eligibility for treatment with thrombolysis [45]. Correct treatment decisions were made in similar proportions in both groups (telemedicine: 85% correct; telephone: 89% correct). There was no significant difference in mortality, 90-day functional outcome, use of thrombolysis, rate of intracerebral hemorrhage after treatment with thrombolysis or evaluation times between the two arms of the trial. No consultations were aborted but technical problems occurred in 74% of telemedicine consultations compared with none in telephone consultations. None of the technical issues prevented correct treatment decisions but some did impact on the time to treatment decision [45].

Walter *et al.* randomized 100 patients to receive prehospital care via a telemedically assisted mobile stroke unit (MSU) (equipped with a CT scanner, point-of-care laboratory and telemedicine connection) or optimized conventional emergency care. The primary endpoint of median (IQR) time from alarm to therapy decision was significantly reduced in the MSU group (35 [31–39] min) compared with the conventional care group (76 [63–94] min; $p < 0.0001$). Secondary end

Table 4. Studies comparing telemedicine with on-site acute stroke management.

Study (year); n	Subjects and study design	Results	Conclusions	Ref.
Mikulik *et al.* (2006); n = 8	Comparison of telemedicine-guided and in-person carotid and transcranial Doppler ultrasound for eight stroke patients using dual video screens transmitting real-time Doppler ultrasound images and sound	In-person and telemedicine-guided Doppler ultrasound successfully examined 100% of internal carotid and middle cerebral arteries, 50 vs 44% of anterior cerebral arteries and 100 vs 88% of basilar arteries, respectively; telemedicine-guided Doppler ultrasound correctly identified all normal examinations in seven subjects; in one patient, telemedicine-guided Doppler ultrasound identified carotid occlusion but misread flow grades in both middle cerebral arteries; median time for in-person vs telemedicine-guided Doppler ultrasound was 15 min (range: 10–35 min) and 30 min (range: 15–50 min) for carotid Doppler ($p = 0.07$) and 18 (range: 15–30 min) and 45 min (30–55 min) for transcranial Doppler ($p = 0.002$), respectively	Carotid and transcranial Doppler ultrasound by an inexperienced health professional guided by a sonographer via telemedicine is feasible	[29]
Audebert *et al.* (2006); n = 225	Comparison of thrombolysis administration by telemedicine in 115 patients at 12 community hospitals (connected to two stroke centers via a digital network including a two-way video conference system and CT/MRI image transfer with high-speed data transmission) and by on-site stroke specialists in 110 patients at two stroke centers	Thrombolysis rates were 2.4% by telemedicine and 5.8% in stroke centers; mean onset to admission times were shorter in the community hospitals versus stroke centers despite longer distances (64 min [SD: 26 min] vs 74 min [SD: 31 min]; $p < 0.01$) but mean door-to-needle times were longer in the community hospitals (68 min [SD: 23 min] vs 61 min [SD: 23 min]; $p = 0.03$); there were no significant differences in mortality (3.5 vs 4.5%; $p = 0.74$) or hemorrhage rates (7.8 vs 2.7%; $p = 0.14$)	Although telemedicine provided a lower rate of systemic thrombolysis, there was no evidence of lower treatment quality	[30]
Audebert *et al.* (2006); n = 3122	Comparison of stroke care for 1971 patients managed in five community hospitals included in a network with telemedical support by two academic hospitals and 1151 patients managed in five matched control community hospitals without specialized stroke care	Patients managed in hospitals within a telestroke network had increased rates of diagnostic investigations, stroke treatments and discharge home, and reduced length of stay and in-hospital mortality; after 3 months, 44% of patients treated in network hospitals versus 54% treated in control hospitals had a poor outcome ($p < 0.0001$); in multivariate regression analysis, treatment in network hospitals independently reduced the probability of a poor outcome (OR: 0.62; 95% CI: 0.52–0.74; $p < 0.0001$)	Telemedical networks with academic stroke centers offered new and innovative approaches to improve acute stroke care at community level for stroke patients living in nonurban areas	[31]
Ionita *et al.* (2009); n = 155	Comparison of telemedicine for 27 patients receiving thrombolysis presenting to one of ten 'spoke' hospitals and on-site specialist stroke assessment for 128 patients receiving thrombolysis at one 'hub' hospital	Treatment at 'hub' or 'spoke' did not have a significant impact on mortality (10.9 vs 11.1%; $p = 0.34$), hemorrhage (20.3 vs 33.3%; $p < 0.35$), outcome (52.3% mRS: 0–3 vs 51.9% mRS: 0–3; $p = 0.16$) or length of stay (8.8 vs 10.7 days; $p < 0.23$)	The hub-and-spoke telemedicine model for acute ischemic stroke treatment has similar efficacy and safety outcomes at both hub and spoke centers	[32]
Switzer *et al.* (2009); n = 74	Prospective comparison of internet-based telemedicine for 49 patients receiving thrombolysis presenting to one of nine rural 'spoke' hospitals and on-site specialist stroke assessment for 25 patients receiving thrombolysis at one 'hub' hospital	Hemorrhage rate (2 vs 0%) and mean OTT time (127.6 min [SD: 36.3 min] vs 145.9 min [SD: 47.0 min]) were not significantly different between 'spoke' and 'hub' hospitals	A web-based telestroke system facilitated the safe administration of thrombolytic therapy to stroke patients in rural communities	[33]

CT: Computed tomography; mRS: modified Rankin Scale; OTT: Onset to treatment; SD: Standard deviation.

Table 4. Studies comparing telemedicine with on-site acute stroke management (cont.).

Study (year); n	Subjects and study design	Results	Conclusions	Ref.
Pollock *et al.* (2010); n = 836	Comparison of telemedicine vs bedside delivery of thrombolysis for 836 patients presenting to one of three hospitals with telemedicine via internet for out-of-hours stroke consultation and on-site specialist stroke assessment 'in-hours'	23% of patients assessed by telemedicine received thrombolysis compared with 21% assessed at the 'bedside'; hemorrhage and mortality rates did not differ between the two groups	Telemedicine was as safe as bedside delivery for thrombolysis and permitted remote decision-making and the safe use of thrombolysis at multiple sites with one 'on-call' rota	[34]
Johansson *et al.* (2011); n = 351	Retrospective comparison of thrombolysis for 47 patients assessed via telemedicine in peripheral hospitals with 304 patients assessed on-site at one regional stroke center	Hemorrhage rate (6.4 vs 7.6%), mean OTT (113 vs 122 min), 3-month outcome (47% mRS: 0–1 vs 43% mRS: 0–1) and 3-month mortality (19 vs 13%) was not significantly different between the two groups	Telemedicine can be used to support regional areas with little experience in delivering thrombolysis	[35]
Zaidi *et al.* (2011); n = 142	Comparison of thrombolysis for 83 patients assessed by telemedicine in one of 12 'spoke' hospitals and 59 patients assessed on-site at one 'hub' hospital	Hemorrhage rate (1.2 vs 5.1%), mean OTT (146 vs 157 min), 3-month outcome (35% mRS: 0–1 vs 22% mRS: 0–1) and 3-month mortality (32 vs 31%) was not significantly different between the two groups; mean door-to-needle time was longer in the telemedicine group (90 min [SD: 36 min] vs 68 min [SD: 26 min]; $p < 0.01$)	Telestroke is a viable alternative to in-person evaluation when stroke expertise is not readily available	[36]
Allibert *et al.* (2012); n = 322	Comparison of the efficacy and safety of telemedicine-delivered thrombolysis of acute ischemic stroke in 161 patients presenting to one remote hospital with 161 patients presenting to one neurovascular center	63 patients (39%) received thrombolysis via telemedicine compared with 98 patients (61%) treated at the neurovascular center. Hemorrhage rate (2 vs 5%) and outcome (40% mRS: 0–1 vs 28% mRS: 0–1) did not significantly differ between the two groups	Thrombolysis delivered remotely via telemedicine is safe and effective	[37]
Chowdhury *et al.* (2012); n = 97	Comparison of telemedicine versus bedside delivery of thrombolysis for 97 patients presenting to one hospital with telemedicine via internet for out-of-hours stroke consultation and on-site specialist stroke assessment 'in-hours'	Hemorrhage rate (4 vs 8%) and outcome (42% mRS: 0–2 vs 37% mRS: 0–2) did not significantly differ between the two groups; median process times (admission to brain CT [25 vs 17 min], OTT [125 vs 100 min] and door-to-needle [61 vs 33 min]; $p \le 0.001$) were significantly longer in the telemedicine group	Compared with face-to-face evaluation, telemedicine is feasible for delivery of thrombolysis during 'out-of-hours'	[38]
Yaghi *et al.* (2012); n = 187	Comparison of thrombolysis for 141 patients assessed via telemedicine and 46 patients assessed by on-site stoke specialists	Mean OTT (156 vs 154 min) and mimic rate (8 vs 4%) did not differ significantly between the two groups; mean door-to-needle time (91 vs 72 min; $p = 0.001$) was significantly longer in the telemedicine group	Telemedicine does not increase the challenge of diagnosing stroke mimics	[39]
Bergrath *et al.* (2012); n = 65	Comparison of telemedically assisted prehospital care of 18 stroke patients compared with local regular emergency care of 47 stroke patients	In three out of 18 teleconsultations (17%), partial dropouts of the system occurred; median on-scene time (25 vs 21 min) and contact to hospital arrival time (38 vs 35 min), stroke diagnosis (61 vs 67%) and thrombolysis rates (30 vs 19%) did not differ significantly between the two groups; median stroke-specific items transferred in written form were higher in the telemedicine group (14 vs 5; $p < 0.0001$)	Teleconsultation is feasible but technical performance and reliability need to be improved; telemedically assisted prehospital care provides better stroke-specific information but is not superior to regular emergency care	[40]

CT: Computed tomography; mRS: modified Rankin Scale; OTT: Onset to treatment; SD: Standard deviation.

Table 5. Studies comparing telemedicine with telephone acute stroke management.

Study (year); n	Subjects and study design	Results	Conclusions	Ref.
Handschu *et al.* (2008); n = 151	Prospective comparison of telemedicine for 77 patients and telephone consultation for 74 patients presenting to one of two district hospitals linked to two stroke centers by integrated services digital network	Telemedicine consultation times were longer than by telephone (49.8 vs 27.2 min; p < 0.01); patients assessed by telemedicine had improved diagnostic accuracy (7.1 vs 17.6% requiring correction; p < 0.05), lower mortality (1.3 vs 6.8%; p < 0.05) and similar length of stay (11.4 vs 12.3 days) versus telephone	Telemedicine is superior to telephone consultation	[41]
Pervez *et al.* (2010); n = 214	Retrospective study comparing telemedicine vs telephone consultation for 181 patients who received thrombolysis presenting to 33 'spoke' hospitals in different 'hub and spoke' telenetwork systems	Treatment by telemedicine or telephone did not affect median OTT (140 min [IQR: 44.8 min] vs 140 min [IQR: 59.8 min]; p = 0.89), hemorrhage (4.8 vs 3.1%; p = 0.56), mean length of stay (5.9 days [SD: 3.6 days] vs 5.9 days [SD: 3.8 days]; p = 0.64) or discharge to home outcome (22.7 vs 34.2%; p = 0.15); mortality for all ages was similar but was less for patients >80 years in those evaluated by telemedicine compared with telephone (18.4 vs 42.3%; p = 0.05)	Outcomes in patients treated in 'spoke' hospitals were comparable to those treated directly at a regional stroke center	[42]

IQR: Interquartile range; OTT: Onset to treatment.

points of symptom onset and/or alarm to end of computed tomography, end-of-laboratory analysis, and intravenous thrombolysis for eligible ischemic stroke patients were also significantly reduced in the MSU group (p < 0.0001). There was no substantial difference in the number of patients who received intravenous thrombolysis, but 12 patients in the MSU group received thrombolysis 'in the field'. Neurological outcomes and safety end points were similar across the groups [3].

Follow-up studies

Both the TEMPiS and STRokE-DOC investigators have carried out follow-up studies to assess the long-term safety of providing acute stroke care via a network with telemedicine support and tele-thrombolysis. Over a 30-month period, the TEMPiS investigators followed-up 1938 stroke patients managed in five community hospitals participating in the TEMPiS network with telemedical support from two stroke centers and 1122 patients managed in five matched, control hospitals. Using multivariable regression analysis they showed that there was a significant reduction in death and dependency at 12 months (OR: 0.65; 95% CI: 0.54–0.78; p < 0.01) and 30 months (OR: 0.82; 95% CI: 0.68–0.98; p = 0.031) for patients managed in TEMPiS hospitals compared

Table 6. Study comparing landline versus mobile telemedicine for acute stroke care.

Study (year); n	Subjects and study design	Results	Conclusions	Ref.
Audebert *et al.* (2008); n = 223	Comparison of 127 hospital-based two-way videoconference patient consultations (using secured digital subscriber landline connection) with 96 mobile telemedicine consultations (using a laptop computer equipped with access protection and headset providing a one-way spoke-to-hub video transmission)	Mean duration of videoconference (11 min [3 min] vs 10 min [3 min]; p = 0.07) and total teleconsultation (44 min [19 min] vs 45 min [21 min]; p = 0.98) was similar for hospital-based and mobile telemedicine. Video and audio quality was rated better for hospital-based telemedicine but this did not affect the ability to make remote clinical decisions such as initiating thrombolysis (17 vs 13%; p = 0.25)	Teleconsultation using a laptop workstation and broadband mobile telecommunication was feasible and allowed remote clinical decision-making	[43]

with control [46]. In a separate follow-up study, the TEMPiS investigators also demonstrated 6-month mortality rates (14.2 vs 13%; $p = 0.45$) and functional outcomes (modified Rankin Scale [mRS]: 0–1; 39.5 vs 30.9%; $p = 0.10$) to be similar in 170 acute ischemic stroke patients treated by thrombolysis via telemedicine and 132 patients treated on-site in a stroke center [47]. The STRokE-DOC investigators followed-up 75 of the 222 trial patients and found no difference in 6-month (3 vs 3%; $p > 0.99$), 1-year (8 vs 5%; $p = 0.67$) or 4-year (16 vs 27%; $p = 0.40$) mortality or 6-month (mRS: 0–1; 34 vs 50%; $p = 0.23$), 12-month (mRS: 0–1; 36 vs 53%; $p = 0.23$) or 4-year functional outcome (mRS: 0–1; 35 vs 38%; $p > 0.99$) between patients randomized to telemedicine or telephone consultation [48].

Discussion

This systematic review shows that a variety of cross-sectional, longitudinal and randomized controlled studies has been carried out to investigate the role of telemedicine for the assessment and management of stroke patients. All studies were undertaken in the last decade with over 30 studies investigating more than 18,000 patients presenting with acute stroke. Early studies demonstrated that telemedical management of acute stroke was safe, feasible and acceptable, and more recent randomized studies confirmed the effectiveness of telemedicine and its ability to reduce geographical differences, increase diagnostic accuracy and uptake of thrombolytic treatment. Indeed, a pooled analysis of the 276 patients in the STRokE DOC and STRokE DOC Arizona telestroke trials confirmed the benefits shown in the individual studies [49] and stroke management guidelines advocate its use [50]. While all studies emphasized the benefits of telestroke, it should be borne in mind that a number of studies showed increases in evaluation time by telemedicine, with lengthened door-to-needle and onset-to-treatment times, and increased rates of technical difficulties that sometimes necessitated abortion of attempted patient consultation [13,29,45]. In addition, a subanalysis of the TEMPiS study showed worse outcome for the 16 patients with basilar artery occlusion admitted to telemedically linked general hospitals with subsequent stroke center transfer compared with the 23 patients directly admitted to a stroke center for angiographic intervention [51].

While some studies showed telemedicine systems to facilitate stroke care for a single hospital and its catchment area, it is becoming increasingly common for telemedicine-delivered stroke care to exist and be effective within a hub and spoke model in a geographically organized network [1]. A stroke center acts as a hub that provides specialist care for spoke hospitals that lack 'in-house' stroke expertise. 24-h access to stroke specialists may therefore be achieved with a realistic number of clinicians and unnecessary patient transfer is avoided. However, stroke specialists acting as telemedicine practitioners require on-site healthcare professionals' participation to facilitate the clinical evaluation of the patient and these individuals need to be trained in working with remote specialists to obtain accurate neurological assessments [52]. Within the hub and spoke service network, models for telemedicine with and without secondary transfer exist but there is no controlled trial data to support either approach [53]. Overall, the published studies support the effectiveness of highly organized and structured telemedicine networks for extending expert stroke care into rural remote communities lacking sufficient neurological expertise with high acceptance amongst co-operating healthcare providers [45,54]. The TEMPiS study involved a system of specialized stroke wards, continuing education, and telemedicine in community hospitals, demonstrated benefit up to 30 months [46].

Telestroke networks involve a considerable number of personnel (including both healthcare professionals and information technologists), telemedicine equipment, internet-based subscriptions and training overheads. In 2010, the National Health Service Stroke Improvement Programme developed a governance framework to support the implementation and delivery of a telemedicine system in acute stroke, focusing on the importance of training, education, performance and risk management [103]. Miley *et al.* suggested that the start-up and first year of operation cost for a multihub network serving 35 rural spoke hospitals is US$2.5 million [55] and Ehlers *et al.* recommended that the additional total costs to hospitals of implementing thrombolysis via telemedicine are approximately US$3.0 million per year in the case of five centers and five satellite clinics or US$3.6 million per year based on seven centers and seven satellite clinics [56]. Fanale *et al.* commented that the annual cost of adding a rural spoke hospital to a telestroke network may vary from less than US$10,000 to US$200,000, depending on the size of hospital, volume of stroke consultations and sophistication of telemedicine equipment selected [57]. In the current times of austerity, outlays of this magnitude for healthcare providers are fraught with difficulty. However, recent studies have suggested telemedicine to be cost-effective in the long term. Ehlers *et al.* calculated the incremental cost–effectiveness ratio to be approximately US$50,000 when taking a short-term perspective (1 year) but thrombolysis was dominant (both cheaper and more effective) after as little as 2 years [56]. The authors projected cost–effectiveness to improve with time as macroeconomic costs balanced with savings in care and rehabilitation, although long-term calculations were uncertain. Nelson *et al.* combined quality-adjusted life-years (QALYs) gained with costs to generate incremental cost–effectiveness ratios and in the base case analysis, compared with usual care, telestroke resulted in an incremental cost–effectiveness ratio of US$108,363/QALY in the 90-day horizon and US$2449/QALY in the lifetime horizon [58]. The authors concluded that when a lifetime perspective is taken, telestroke appears cost-effective compared with usual care, since telestroke costs are upfront but benefits of improved stroke care are lifelong.

The limitations of this review include the small number of studies, particularly of a randomized design. Publication bias, in terms of studies with positive results being published at the expense of those with negative results, also needs to be taken into account in view of the published studies' results emphasizing the benefits and not the problems associated with telemedicine for stroke. Finally, the authors are aware that no studies were published before 2002.

Conclusion

Telemedicine is not a new form of therapy but it has provided an exciting medium whereby evidence-based treatments for stroke care, including thrombolysis, can be delivered more effectively to a wider population than before. Indeed, using telemedicine, a stroke specialist can assess a patient within minutes of arrival to hospital helping to meet the demands of the 'time is brain' concept in acute ischemic stroke care [52]. The promise of telestroke thus aims to avoid unnecessary patient transfer, bring the specialist to the patient, reduce inequality of healthcare access through stroke consultation and increase the number of patients being treated acutely with thrombolysis.

Future perspective

As technology becomes more advanced, so telestroke programmes are expected to develop further. Indeed, while 12 telestroke networks were functioning in the USA in 2009, this number had increased to 97 by 2012 [1,59]. Furthermore, recent studies have demonstrated the feasibility of using smart phones for remote clinical and radiological assessment of stroke patients [9,10] and telestroke has now been shown to be possible in the prehospital phase of the stroke patient's journey, as well as in the emergency department [3]. The evidence appears to be robust for delivering hyperacute interventions such as thrombolysis but other medical interventions such as secondary prevention also require evaluation. The challenge now is to translate what research evidence is available for telestroke into clinical practice and to maintain high standards of governance while doing so.

Financial & competing interests disclosure

The authors have no relevant affiliations or financial involvement with any organization or entity with a financial interest in or financial conflict with the subject matter or materials discussed in the manuscript. This includes employment, consultancies, honoraria, stock ownership or options, expert testimony, grants or patents received or pending, or royalties.

No writing assistance was utilized in the production of this manuscript.

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