The challenge of acute-stroke management: Does telemedicine offer a solution?

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Abstract Background **Several studies have described successful experiences with the use of telemedicine in acute stroke. The objective of this study was to assess the feasibility, acceptability, and treatment delivery reliability, of telemedicine systems for the clinical and radiological assessment, and management of acute-stroke patients.**

Summary of Review **A systematic review of the literature was carried out. Studies were included if they met the following criteria: (1) study population included participants with a diagnosis of suspected acute stroke, (2) intervention included the use of telemedicine systems to aid assessment, diagnosis, or treatment in acute stroke, and (3) outcomes measured related to feasibility in clinical practice, acceptability to patients, carers, and staff, reliability of telemedicine systems, and effectiveness in delivering treatment, especially tissue plasminogen activator (tPA). Overall, 17 relevant non-randomised studies reported that telemedicine systems were feasible and acceptable. Interrater reliability was excellent for global clinical assessments and decisions on radiological exclusion criteria although agreement for individual assessment items was more variable. Telemedicine systems were associated with increased use of tPA.**

Conclusion **Although there is limited reliable evidence, observational studies have indicated that telemedicine systems can be feasible, acceptable, and reliable in acute-stroke management. In addition, telemedicine consultations were associated with improved delivery of tPA.**

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Introduction

The management of acute stroke is evolving rapidly. This is in part due to the licensing of tissue plasminogen activator (tPA) such that the European approval definitions permit tPA administration within 3 h of stroke onset for appropriate patients with a relevant neurological deficit, but only under specialist care (1). This has led to a need for more rapid specialist assessments to be carried out in acute stroke.

A timely accurate diagnosis of stroke is dependent on a detailed patient history, neurological examination, imaging [computerised tomography (CT) or magnetic resonance imaging (MRI) scan], and expert interpretation, all, within a very limited time frame. This requires stroke physicians, radiologists, and imaging-study technicians to be readily available. However, such resources are not currently available in all hospitals. tPA thrombolysis is, therefore, offered primarily in academic stroke departments (SITS – http://www.acutestroke.org). The major reason for patients not receiving intravenous thrombolytic therapy is arrival at appropriate services after the 3-h window (2). Countries with centralised, specialist neurological services such as Germany and the United States tend to have developed, centralised stroke centres. These centres can focus specialist expertise, but have the disadvantages of fragmenting the patient journey and requiring many patient transfers. In countries like the United Kingdom and in Scandinavia, where such services are more decentralised, there is an ongoing challenge to provide sustainable rapid expert assessment. One potential alternative to centralised stroke centres is telemedicine networks.

Telemedicine has been defined as 'the use of telecommunication technologies to provide medical information and services' (3) or 'the process by which electronic, visual, and audio communications are used to provide diagnostic and consultation support to practitioners at distant sites, assist in or directly deliver medical care to patients at distant site, and enhance the skills and knowledge of distant medical care providers' (4). Levine and Gorman (5) have proposed the term 'telestroke' for the use of telemedicine in acute-stroke intervention. Unlike teleradiology, which has been widely accepted in practice for several years, the uptake for telemedicine has been slow.

In principle, telemedicine might be of value in acute stroke. We, therefore, performed a systematic review of the available evidence on the role of telemedicine in the assessment and management of patients with acute stroke. In particular, we investigated the feasibility, acceptability and reliability of telemedicine in the clinical and radiological assessment, and management of acute-stroke patients.

Selection criteria

We included all prospective and retrospective studies that met the following criteria: (1) study population included those with a diagnosis of suspected acute stroke, (2) intervention included the use of telemedicine systems (defined as 'the use of telecommunications technology to provide medical information and services') to aid assessment, diagnosis or treatment in acute stroke, and (3) outcomes measured related to feasibility [systems were able to work in clinical practice (e.g. system failures, system delays)], acceptability (acceptable to patients, carers, and staff), reliability (able to allow accurate clinical and radiological assessment), and effectiveness in delivering treatment [able to increase delivery of acute treatments (especially tPA)]. Although we focused on English language studies, we did not exclude any studies on the basis of language.

Search strategy

We conducted an extensive search on all major electronic databases from inception to January 2006: Medline, BIDS (EMBASE), the Cumulative Index to Nursing and Allied Health Literature print index (CINAHL), the Cochrane Library, and the database of Telemedicine Information Exchange. Relevant keywords and permutations of search terms relating to telemedicine were combined with those relating to acute stroke. This was supplemented by using the Web of Science database to generate a list of articles that cited identified original studies. In addition, we also carried out hand searching of reference lists and recent conference proceedings (European Stroke Congress, American Heart Association 2001–2005).

Synthesis of outcomes

One author (O. W.) excluded obviously irrelevant references, then both authors independently screened all the remaining studies. Relevant studies were retrieved in full text; detailed data extraction was carried out, and the quality of the studies was assessed. In order to maintain a consistency of reporting, a validated generic checklist designed for quantitative studies was used to assess the quality of all the studies included in the review (6). This checklist included 14 criteria, which are consistent with the recommendations from the Centre for Reviews and Dissemination (CRD), and the consensus statement of meta-analysis reporting observational studies in epidemiology (7, 8). Any disagreement relating to inclusion of studies, data extraction or quality assessment between the reviewers was resolved by discussion. We categorised the studies according to the telemedicine network system, and where multiple publications referring to the same telemedicine network were found, we summarised and reported on the relevant data. Meta-analysis was planned if appropriate data were available; if not, we planned to tabulate comparable results.

Review profile

The search strategy identified 155 studies; 132 did not meet the inclusion criteria and were excluded, and 18 were retrieved for full text assessment. Following the exclusion of one case report (9) 17 studies met our inclusion criteria and were included in the review (Table 1). No completed randomised controlled trials were found (although one randomised controlled trial and one cluster randomised controlled trial are known to be ongoing). The included reports were observational studies of telemedicine networks for stroke care that have been implemented in the United States, Germany, and France. Generally, these systems described connections between remote locations and stroke centres through videoconference including transfer of clinical data such as CT or MRI scans. In one study, a telephone network was described (23). The literature primarily consisted of reports of experiences from four telemedicine networks: the Telemedic Pilot Project for Integrative Stroke Care (TEMPiS) (10–12) and the Telemedicine in Stroke in Swabia (TESS) (26) based in Germany and Telemedicine for the Brain Attack Team (TeleBAT) (13, 14) and the Remote Evaluation for Acute-Ischaemic Stroke (REACH) program based in the United States (15–17).

Feasibility and acceptability

All the telemedicine networks reported a positive experience, suggesting that implementation of such systems was feasible and acceptable. In particular, TEMPiS demonstrated a consistent increase in the use of teleconsultation over time – the number of teleconsultations increased from 104 in the first month to 251 in the 12th month (12). Although technical failures have been reported, they were uncommon (0–4% of consultations). Clinician satisfaction relating to imaging and audio quality, and patient satisfaction was reported to be good (13, 25, 18). The majority of local physicians (93%) and remote stroke specialists (88%) in TESS felt that telemedicine makes relevant contribution to the diagnostic work-up, CT assessment (76% in both groups), and therapeutic decisions (80% and 88%, respectively) (18).

The three studies that reported consultation times (TEMPiS, TESS, and a network in France) had an average teleconsultation duration of 15 min (11, 18, 19). Direct comparison has shown significantly shorter duration of assessment associated with remote neurological assessment via a teleconsultation system compared with bedside assessment (9·7 vs. 6·6 min; $P < 0{\cdot}001$).

Table 1 Telemedicine networks in stroke care

	Telemedicine system	Feasibility and acceptability	Reliability and validity	Effective treatment delivery
TEMPiS (Germany) (10–12)	Two-way videoconference and CT/MRI image transfer between two stroke centres and 12 regional hospitals	Mean $\pm$ SD consultation time was $15{\cdot}6 \pm 8{\cdot}2$ min		tPA delivered in 191 patients (of 8935 stroke patients, 4621 had telemedicine consultations) Mean door-to-needle time was 68 min in telemedicine group compared with 62 min in stroke centres
TeleBAT (US) (13, 14)	Two-way videoconference and CT image transfer between a rural hospital and the Brain Attack Centre (160 Km). The effectiveness in the delivery of treatment was compared between telemedicine ($n = 23$) and telephone consultation ($n = 27$) A later study evaluated the reliability and effective treatment delivery using a two-way videoconference and CT image transfer between an ambulance unit and a hospital. Two actor patients with stroke mimicked 12 stroke scenarios. Data were compared against a control group that had been evaluated and treated with tPA	Post-transfer interview questionnaire reported positive statements from patients and staff Two technical failures in telemedicine group	Good validity – one examiner reported $>80\%$ agreement between viewing via TeleBAT and TV/VCR videos in 17/19 NHSS items; the other reported complete agreement in all 19 items Good reliability – interrater reliability was also high ($k > 0{\cdot}5$)	tPA delivered in 5/21 patients in the telemedicine group compared with 1/27 in the telephone consultation group. Mean $\pm$ SD time-to-treatment was 17 ± 4 min with the TeleBAT group compared with 33 ± 17 min with the controls ($P = 0{\cdot}0033$)
REACH (US) (15–17)	Remote video evaluation via the internet between neurologist and eight rural locations	Mean assessment time was 6·43 min bedside compared with 9·11 min remote assessment	Reliability test comparing bedside and remote NIHSS assessment ($n = 20$) showed strong correlation between the two types of assessment ($r = 0{\cdot}95$; $P = 0{\cdot}00001$)	tPA delivered in 30 patients (of 194 consultations) Mean onset-to-treatment time was 122 min No symptomatic intracerebral haemorrhage was recorded
TESS (Germany) (18)	Videoconference link of seven rural hospitals to one stroke unit, covering a distance of 53 to 137 Km ($n = 153$)	Mean consultation time was 15 min. Good user satisfaction. Good/very good patient satisfaction No technical failures		tPA delivered in two patients (11 discussed)

RUN-stroke Berthier *et al*. (France) (19)	The RUN-stroke experiment – two-way videoconference between the remote and local teams Reliability assessment – bedside vs. remote NIHSS assessment by neurologists ($n = 28$)	Mean consultation time was 15 min (range 7–22)	Good validity and reliability reported Global concordance between neurologists was 0·93 Good to excellent agreement on all items (weighted kappa $> 0{\cdot}61$) Global concordance between non-neurologists was 0·85 Good to excellent agreement for all items (weighted kappa $> 0{\cdot}47$)	
Handschu *et al*. (Germany) (20)	Video-based remote examination ($n = 54$) vs. telephone consultation ($n = 56$) Reliability assessment – bedside vs. remote NIHSS assessment ($n = 41$); patients admitted in emergency room within 36 h of symptom onset	Mean consultation times were 34·8 min with video-based examinations compared with 20·6 min with telephone consultations Mean assessment times were 11·4 min (range 8–18) bedside compared with 10·8 min (range 7–18) remote ($P = 0{\cdot}013$) Minor technical problems in two cases	Excellent agreement for all items – weighted $k = 0{\cdot}85$ to 0·99 Good to excellent for acute patients ($n = 12$) – weighted $k = 0{\cdot}62$ to 1·0	Four (7%) patients were transferred from the video group compared with 8 (14%) from the telephone group
Meyer *et al*. (US) (21)	Site-independent and wireless telemedicine system Reliability assessment – bedside vs. remote NIHSS assessment ($n = 25$) patients	No technical failures recorded	Good reliability and validity Close correlations (Spearman $r \geq 0{\cdot}93$) for both scores Excellent agreement for 10/15 NIHSS items ($k = 0{\cdot}67$) and 9/11 mNIHSS items ($k = 0{\cdot}82$)	
Shafqat *et al*. (US) (22)	Remote assessment through audio-video link Reliability assessment – bedside vs. remote NIHSS assessment by neurologists ($n = 20$); hospitalised patients, two to seven days after stroke	Mean assessment time was 6·55 min (range 4–12) with bedside consultations compared with 9·70 min (range 6–18) with remote consultations ($P < 0{\cdot}001$)	Good reliability demonstrated Bedside and remote examinations did not differ on any patient by > 3 points Strong linear correlation between bedside and remote examinations ($r = 0{\cdot}97$; $P < 0{\cdot}001$) Excellent agreement reported for orientation, motor arm, motor leg and neglect (weighted $k = 0{\cdot}75$ to 1·0); good agreement for language, dysarthria, sensation, visual fields, facial palsy and gaze (weighted $k = 0{\cdot}4$ to 0·75); poor to no agreement was reported for level of arousal, commands, and ataxia (weighted $k < 0{\cdot}4$)	

Frey *et al*. (US) (23)	Telephone consultation network between rural hospital and neurological institute, covering a distance up to 450 Km			tPA delivered in 53 telemedicine patients compared with 73 patients in-house Mean door-to-needle time was 90 min with telemedicine group compared with 80 min in-house ($P = 0{\cdot}10$)
Johnston *et al*. (US) (24)	Reading of consecutive CTs ($n = 60$) via teleradiology (scan files transmitted electronically to a remote monitor where the neurologists read the images) vs. light box (readings of hard copies on a view box) by neurologists. Both were compared with the gold standard (official read by neuroradiologist)		Good reliability demonstrated t-PA eligibility sensitivity 100% (93% to 100%) and specificity 100% (40% to 98%); complete agreement for both comparisons; $k = 1{\cdot}0$ Neurologists in both groups identified the same four haemorrhages from the CT scans	
Schwamm *et al*. (US) (25)	Two-way videoconference between stroke consultants and emergency physicians at an island-based critical access hospital Stroke consultants reviewed suspected acute stroke patients within three hours; documented NIHSS, reviewed tPA eligibility, viewed head CT, and provided recommendations on management ($n = 24$)	Physicians satisfied with the quality of sound, image and connection speed – >95% Physicians confident with the system – 100% Physicians believed in improved patient care – 100% Patients believed that it was as good as face-to-face consultations – 85·7% Overall, a 4·2% transmission failure rate was reported	'Very good' agreement among all remote readers Complete agreement on radiological exclusions for tPA and for detecting one subdural haemorrhage	tPA delivered in 6 patients (8 potentially eligible) Transfer avoided in 11 patients Mean $\pm$ SD consult-to-needle time was 36 ± 15 min Mean $\pm$ SD door-to-needle time was 106 ± 22 min

CT, computerised tomography; MRI, magnetic resonance imaging; SD, Standard deviation; TPA, Tissue plasminogen activator; NIHSS, National Institutes for Health Stroke Scale; MNIHSS, Modified National Institutes of Health Stroke Scale.

Reliability

Seven studies attempted to evaluate the reliability of clinical assessments via a telemedicine network. Interrater reliability between face-to-face and remote evaluation of the National Institute of Health Stroke Scale (NIHSS) was assessed in five studies (16, 19–22). All the studies reported good or excellent agreement and strong linear correlation between the total scores. The individual NIHSS items that showed poor agreement (e.g., ataxia) appeared to be those showing poor agreement on face-to-face assessment (21).

Similar findings were reported in two studies that evaluated the interrater reliability between face-to-face and remote CT scan interpretation (25, 24). Both studies reported complete agreement between telemedicine assessment and conventional neuroradiology regarding eligibility for thrombolysis and major exclusions.

Effectiveness in the delivery of treatment

The improved delivery of tPA has been reported to be one of the key benefits of telemedicine networks. The TEMPiS study reported that 86 patients received tPA in the first 12 months compared with 10 before the introduction of telemedicine. The mean door-to-needle time was 78 min (SD 23), and in-hospital mortality was 12·6% (11, 12). A separate analysis of the first 106 TEMPiS patients receiving tPA reported a mean door-to-needle time of 76 min (SD 24) and in-hospital mortality of 10·4%. However, symptomatic haemorrhage rate was reported in 8·5% patients (11). In the REACH study, 194 acute-stroke consultations took place over a 2-year period and 30 received tPA at a mean onset-to-treatment time of 122 min. No intracranial haemorrhage was recorded (17). In another study, of the eight potentially eligible patients, six received tPA with a mean door-to-needle time of 106 min (25). Similar door-to-needle times between patients managed via a telephone consultation network (53 patients with a mean time of 90 min) and those managed in-house at a stroke centre (73 patients with a mean time of 80 min) has also been reported ($P = 0{\cdot}10$) (23).

Comments

Telemedicine networks usually consist of establishing connections between remote locations and specialist advice through different types of videoconferencing and clinical data transfer. The literature on telemedicine in acute-stroke care has described successful experiences from France, Germany and the United States. The reported findings suggested that telemedicine stroke networks can be feasible to implement, acceptable to local physicians, stroke specialists, and patients, and potentially reliable in the assessment of stroke. In some cases, the benefits of using telemedicine networks have been associated with an improved delivery of tPA, reduced patient transfers, and probably speeding up assessments (if transfer patient times are taken into account).

However, our review has several limitations. There is an absence of published randomised controlled trials to formally assess impact of the implementation of telemedicine networks in the management of acute stroke. The studies in the current literature primarily consisted of cohort studies describing experiences of telemedicine networks in stroke management. Although these studies are informative, the overall methodological quality of the studies is limited. In particular, the effects of potential sources of bias such as patient selection and confounding factors have not been addressed thoroughly.

Disparities exist in access to healthcare due to geographical barriers and limited resources and rural locations often lack the resources for adequate emergency stroke treatment. The studies reported here demonstrate the potential for telemedicine to address some of these resource disparities. In addition, providing 24-h specialist consultant support for acute-stroke services is an increasing practical challenge. Telemedicine services may offer a way of sharing specialist consultant cover over a wider geographical area.

Despite the generally positive message, there are still potential barriers to implementing such systems. There is some scepticism about the technical quality of the remote connections and in general, both physicians and patients prefer face-to-face consultations. Despite the simplicity of setting up modern telemedicine systems, healthcare professionals would still require appropriate training in the use of the system. Some studies reported the cost of implementing the telemedicine system (11, 12, 17). However, none evaluated the cost effectiveness of telemedicine in stroke. Until the cost effectiveness of implementing telemedicine systems is made clear, the absence of such information may remain a barrier to adopting the use of telemedicine in stroke management.

How might a telemedicine system actually operate in acute stroke? Based on the existing reports, a feasible approach may be to have a group of stroke physicians contributing to a specialist service centred on a specialist 'hub' site(s) and several 'spoke' sites (with available CT scanning and multi-disciplinary stroke unit). The stroke physicians would contribute to an on-call rota, and the telemedicine consultation would determine if treatment is given in the referring hospital or transfer arranged to the 'hub' site. This could disseminate specialist expertise over a wider area, speed up treatment with tPA and minimise unnecessary transfers.

There is an obvious need for proper randomised controlled trials to determine the clinical and cost effectiveness of telemedicine in relation to outcomes such as delivery of tPA, reduced patient transfer, and improved quality of care. Until the results of randomised controlled trials are available, we have only observational studies to guide decision making. Telemedicine services appear to offer a promising approach to improve access to acute assessment and treatment particularly, in situations where the healthcare economy does not favour stroke centres, where populations are dispersed and local hospital stroke services are already well established.

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References

1 Sacco RL, Adams R, Albers G *et al.* Guidelines for prevention of stroke in patients with ischemic stroke or transient ischemic attack: a statement for healthcare professionals from the American Heart Association/American Stroke Association Council on Stroke: co-sponsored by the Council on Cardiovascular Radiology and Intervention: the American Academy of Neurology affirms the value of this guideline. *Stroke* 2006; **37:**577–617.
2 Kwan J, Hand P, Sandercock P: A systematic review of barriers to delivery of thrombolysis for acute stroke. *Age Ageing* 2004; **33:**116–21.
3 Perednia DA, Allen A: Telemedicine technology and clinical applications. *JAMA* 1995; **273:**483–8.
4 Lambrecht CJ: Emergency physicians' roles in a clinical telemedicine network. *Ann Emerg Med* 1997; **30:**670–4.
5 Levine SR, Gorman M: "Telestroke": the application of telemedicine for stroke. *Stroke* 1999; **30:**464–9.
6 Kmet LM, Lee RC, Cook LS: Standard Quality Assessment Criteria for Evaluating Primary Research Papers from a Variety of Fields. Alberta: Alberta Heritage Foundation for Medical Research, 2004.
7 Stroup DF, Berlin JA, Morton SC *et al.* Meta-analysis of observational studies in epidemiology: a proposal for reporting. Meta-analysis of Observational Studies in Epidemiology (MOOSE) group. *JAMA* 2000; **283:**2008–12.
8 NHS Centre for Review and Dissemination: Undertaking systematic reviews of research on effectiveness: CRD's guidance for those carrying out or commissioning reviews. 2nd Edition ed: University of York, 2001.
9 Choi JY, Wojner AW, Cale RT, Gergen P, Degioanni J, Grotta JC: Telemedicine physician providers: augmented acute stroke care delivery in rural Texas: An initial experience. *Telemed J e-Health* 2004; **10**(Suppl. 2)**:** 90–4.
10 Audebert HJ, Schenkel J, Kukla C, Ziemus B, Haberl R, Furst A: Advances and limitations of Telestroke the Telemedic Pilot Project for Integrative Stroke Care (TEMPiS). *Cerebrovasc Dis* 2005; **19**(Suppl. 2)**:** 1–159.
11 Audebert HJ, Kukla C, Von Claranau SC *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:**287–91.
12 Audebert HJ, Wimmer ML, Hahn R *et al.* Can telemedicine contribute to fulfill WHO Helsingborg Declaration of Specialized Stroke Care? The Telemedic Pilot Project for Integrative Stroke Care (TEMPiS) in Bavaria. *Cerebrovasc Dis* 2005; **20:** 362–9.
13 LaMonte MP, Bahouth MN, Hu P *et al.* Telemedicine for acute stroke: triumphs and pitfalls. *Stroke* 2003; **34:**725–8.
14 LaMonte MP, Xiao Y, Hu PF *et al.* Shortening time to stroke treatment using ambulance telemedicine: TeleBAT. *J Stroke Cerebrovasc Dis* 2004; **13:**148–54.
15 Wang S, Gross H, Lee SB *et al.* Remote evaluation of acute ischemic stroke in rural community hospitals in Georgia. *Stroke* 2004; **35:**1763–8.
16 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:** 188–92.
17 Hess DC, Wang S, Hamilton W *et al.* REACH: Clinical feasibility of a rural telestroke network. *Stroke* 2005; **36:**2018–20.
18 Wiborg A, Widder B: Teleneurology to Improve Stroke Care in Rural Areas the Telemedicine in Stroke in Swabia (TESS) Project. *Stroke* 2003; **34:**2951–7.
19 Berthier E, Decavel P, Christiano M *et al.* Evaluating the reproducibility and routine use of the NIHSS by telemedicine with the emergency neurology network (RUN-STROKE) programme. *Cerebrovasc Dis* 2005; **19**(Suppl. 2)**:** 59.
20 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:**2842–6.
21 Meyer BC, Lyden PD, Al-Khoury L *et al.* Prospective reliability of the STRokE DOC wireless/site independent telemedicine system. *Neurology* 2005; **64:**1058–60.
22 Shafqat S, Kvedar JC, Guanci MM, Chang Y, Schwamm LH: Role for telemedicine in acute strokea: feasibility and reliability of remote administration of the NIH stroke scale. *Stroke* 1999; **30:**2141–5.
23 Frey JL, Jahnke HK, Goslar PW, Partovi S, Flaster MS: tPA by telephone: extending the benefits of a comprehensive stroke center. *Neurology* 2005; **64:**154–6.
24 Johnston KC, Worrall BB: Teleradiology Assessment of Computerized Tomographs Online Reliability Study (TRACTORS) for acute stroke evaluation. *Telemed J e-Health* 2003; **9:**227–33.
25 Schwamm LH, Rosenthal ES, Hirshberg A *et al.* Virtual telestroke support for the emergency department evaluation of acute stroke. *Acad Emerg Med* 2004; **11:**1193–9.
26 Wojner AW, Morgenstern L, Alexandrov AV, Rodriguez D, Persse D, Grotta JC: Paramedic and emergency department care of stroke: baseline data from a citywide performance improvement study. *Am J Crit Care* 2003; **12:**411–7.