Telemedicine in pre-hospital care: a review of telemedicine applications in the pre-hospital environment

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Abstract

The right person in the right place and at the right time is not always possible; telemedicine offers the potential to give audio and visual access to the appropriate clinician for patients. Advances in information and communication technology (ICT) in the area of video-to-video communication have led to growth in telemedicine applications in recent years. For these advances to be properly integrated into healthcare delivery, a regulatory framework, supported by definitive high-quality research, should be developed. Telemedicine is well suited to extending the reach of specialist services particularly in the pre-hospital care of acute emergencies where treatment delays may affect clinical outcome. The exponential growth in research and development in telemedicine has led to improvements in clinical outcomes in emergency medical care. This review is part of the LiveCity project to examine the history and existing applications of telemedicine in the pre-hospital environment. A search of electronic databases including Medline, Excerpta Medica Database (EMBASE), Cochrane, and Cumulative Index to Nursing and Allied Health Literature (CINAHL) for relevant papers was performed. All studies addressing the use of telemedicine in emergency medical or pre-hospital care setting were included. Out of a total of 1,279 articles reviewed, 39 met the inclusion criteria and were critically analysed. A majority of the studies were on stroke management. The studies suggested that overall, telemedicine had a positive impact on emergency medical care. It improved the pre-hospital diagnosis of stroke and myocardial infarction and enhanced the supervision of delivery of tissue thromboplasminogen activator in acute ischaemic stroke. Telemedicine presents an opportunity to enhance patient management. There are as yet few definitive studies that have demonstrated whether it had an effect on clinical outcome.

Keywords: Telemedicine; Telecare; Telehealth; Teletrauma; Telestroke; eHealth; Mobile health; Pre-hospital care; Emergency medical services; Emergency medicine

Review

Introduction

There is a critical global shortage of healthcare professionals. As a consequence, qualified professionals may not be physically present particularly in under-resourced regions, and providing quality healthcare may be quite challenging. This challenge can be tackled by providing specialist medical services using information and communication technologies to remotely located healthcare workers and patients where such expertise is not immediately available. This is known as telemedicine. In telemedicine, the client is separated from the expert in space [1]. The concept of telemedicine has been used in one form or another for centuries. Smoke signals were used in ancient African villages to alert adjoining villages of disease outbreaks, and bonfires were used to warn of bubonic plague in the Middle Ages in Europe. With advances in telecommunication, newer systems such as the telegraph were used to transmit medical information about epidemics and war casualties. However, the use of telemedicine was facilitated by the invention of the telephone in the nineteenth century. This culminated in one of the earliest recorded uses of information and communication technology (ICT) in telemedicine, when Einthoven, on 7th February 1906, transmitted electrocardiogram (ECG) tracings over...
With a subsequent increase in research since the 1990s, increased telemedicine use over the past 40 to 50 years has led to advances in network infrastructure. Perhaps, the earliest implementation of modern telemedicine was by the National Aeronautics and Space Administration (NASA) in the 1960s when it was used for remote physiological monitoring of astronauts during manned space flights [4]. NASA continued to play a pivotal role in the development of telemedicine with the development of the Space Technology Applied to Rural Papago Advanced Health Care (STARPAHC) project on the Papago Indian Reservation in Arizona, USA, in 1972. The STARPAHC project included a van equipped with an X-ray machine and other medical instruments, and it was staffed by two paramedics. The van was linked by two-way microwave transmission to the Public Health Service Hospital complemented by a remotely located clinic staffed by a physician assistant linked to the control centre in the hospital [5].

After the December 1988 earthquake disaster in Armenia, NASA established the first international telemedicine project known as the Spacebridge to Armenia that allowed telemedicine consultation between medical centres in the United States and Armenia [6]. By the 1970s, the National Library of Medicine funded research into the reliability of telemedicine via satellite communication to 26 sites in Alaska, USA. Improvements in telecommunications technology have led to advances in network infrastructure that enabled the development of high-definition live interactive video-to-video networks such as the European Union-funded LiveCity project. These, in turn, have led to increased telemedicine use over the past 40 to 50 years with a subsequent increase in research since the 1990s.

Telemedicine potentially holds great promise in facilitating emergency medical practice. It is increasingly being used in emergency medicine with an associated increase in published research. It is particularly suited to medical emergencies where treatment delays adversely affect clinical outcome. A typical scenario is ST elevated myocardial infarction (STEMI) where recognition of ECG changes by paramedics could facilitate early intervention and improve clinical outcome. However, recognition of ECG changes of STEMI by paramedics appears to be suboptimal [7], and adverse clinical events that occur during pre-hospital transportation [8] may also benefit from real-time clinician advice. Paramedics in ambulances have used telemedicine links with specialists to facilitate pre-hospital diagnosis and reduce treatment delays in stroke, myocardial infarction, and trauma. Telemedicine has also been used by emergency medicine doctors to supervise remotely located nurse practitioners and general practitioners in minor injury clinics [9].

This literature review is part of the emergency use case of the LiveCity project and analyses published studies to highlight the use of telemedicine in pre-hospital care.

**Methods**

We performed an automated electronic search using the MeSH terms identified in Medline. The terms included the following: Telemedicine, Telecare, Telehealth, Teletrauma, Telestroke, eHealth, mobile Health, Pre-hospital care, and emergency care. The search terms were used as keywords on Medline, Excerpta Medica Database (EMBASE), Cochrane Database of Systemic Reviews (CDSR), Cochrane, and Cumulative Index to Nursing and Allied Health Literature (CINAHL). The search was then finalized using Boolean operators to combine (‘OR’) and cross-reference (‘AND’) between domains. The first ten pages of a basic web search using the Google search engine were analysed for relevant articles. A manual search was done by checking reference lists of selected articles and researching key authors.

Abstracts were independently reviewed by two of the authors, and the full text of articles that met the inclusion criteria were retrieved for further analysis. Included studies were collated and critically analysed based on their methodology and sample size to summarize their results.

Studies carried out between 1970 and 2014 that addressed telemedicine use in the emergency care of trauma, myocardial infarction, and stroke and studies whose outcomes included cost-effectiveness, feasibility, and clinical outcome were included in the review. Case reports and studies that were not published in English and did not address an aspect of emergency medicine were excluded from this review.

**Results**

The initial literature search yielded 1,279 studies. Based on the inclusion criteria, 1,240 were excluded, while 39 were selected for further analysis. Twenty-five of the studies focused on stroke management, while five and nine were on myocardial infarction and trauma, respectively.

We found eight articles that were feasibility studies, while six articles explored the reliability of telemedicine. Four articles addressed the diagnostic accuracy of telemedicine, and three articles explored the use of telemedicine to reduce treatment delays. Thirteen studies used the ‘Hub and Spoke’ model, while five of the studies used a link between an ambulance and a hospital. Twenty-one of the studies reviewed did not clearly define the model used.

Table 1 shows the characteristics of the studies included. We found 2 randomized controlled studies, 10 case-control studies, and 27 observational and descriptive studies (1). The network types used in the studies...
were the following: mobile broadband in 8 and wired broadband in 31 of the studies included. The methodologies and subjects of the studies reflect the nascent nature of research in this field. Early studies address the feasibility, accuracy, and reliability of telemedicine use in clinical settings which have not been fully addressed due to design flaws identified in Tables 2, 3, and 4.

Discussion
There has been an exponential growth in the number of telemedicine articles published since the mid-1990s. This review noted the highest amount of research into telemedicine use in stroke care. Trauma and myocardial infarction have seen much less telemedicine-related research.

Stroke
Telemedicine in stroke management has undergone the most extensive study of all areas examined. Its use is feasible [10,11] but dependent on the technical performance of the telemedicine equipment and broadband infrastructure [12,21]. Due to its novel uses, medico-legal concerns have led to questions about the relevance and clarity of communication during informed consent. However, analysis of video-taped telemedicine consultations of acute stroke patients before intravenous administration of tissue plasminogen activator showed that 80% of observers rated informed consent as adequate [23]. Administration of tissue thromboplasminogen activator (tPA) within 3 to 4.5 h [49–51] of an acute ischemic stroke remains the gold standard in its management. However, this approach is restricted by time constraints and requires the supervision of a clinician with expertise in stroke management, and as a result, there is a disappointingly low utilization of thrombolysis in ischaemic stroke [52,53]. Where available, integrating stroke specialists in pre-hospital stroke response teams significantly reduces time to treatment [54]. This is however not possible in a large proportion of locations where there is a limited availability of stroke specialists. Remote access to a stroke specialist is now possible, and recent studies comparing in-person consultation with remote consultation suggest that telemedicine is a promising solution to the lack of local expertise. The National Institute of Health Stroke Scale (NIHSS) assessment of stroke patients using telemedicine is as reliable as face-to-face assessment [20]. And radiological review of brain CT in stroke management is both feasible and reliable [34]. In the ‘hub and spoke model,’ under served areas where stroke management expertise is lacking (i.e. spoke), telemedicine provides an ideal opportunity for supervision by a centrally located stroke expert (hub). Analysis of clinical outcomes of patients managed using this model suggest that although there is increased consultation, the quality of care remains similar and there was no statistical difference between telemedicine and face-to-face consultation, in short-term [14,15] and long-term [25,26] mortality. In the context of budgetary constraints, a cost-effectiveness analysis indicated that telemedicine is more expensive than usual care [16] partly due to high upfront equipment cost. However, there is the potential for significant cost savings due to reduced length of hospital stay [55].

Trauma
The effects of telemedicine on trauma management have not been as widely studied as in stroke, in the emergency medical services. Telemedicine has been deployed in major disasters such as the Armenian earthquake disaster in 1988. It is well suited to the management of major incidents where an acute deficit of healthcare professionals can be ameliorated by teleconsultation [56]. Where local expertise is lacking, teleradiology has improved diagnosis and reduced expensive transfer of trauma patients [57]. Analysis of the impact of telemedicine on emergency medical services suggests a reduction in mortality and hospital cost [40]. In a hub and spoke model of a central burns unit and three peripheral hospitals, telemedicine use led to increased consultation, but burns assessment was as accurate as face-to-face assessment and reduction in transfers to burns units led to significant cost savings [41]. Interestingly, paramedics that were guided by an emergency medicine clinician could obtain interpretable focused assessment with sonography for trauma (FAST) ultrasound [42], recognize key physical signs, and make better management decisions [43]. The use of a telemedicine
| Authors                  | Journal/title                                      | Methodology                                                                 | Summary of findings                                                                 | Comment                                                                                           |
|--------------------------|---------------------------------------------------|----------------------------------------------------------------------------|-------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------|
| Waite et al. [10]        | Journal of Telemedicine and Telecare               | Multicentre observational study to test the feasibility of telestroke consulting over a wired broadband. Neurologist in an academic centre carried the teleconsult for two peripheral emergency departments | 88 consults with 24 patients receiving t-PA. Demonstrating that telestroke consulting was feasible | This is an observational study that demonstrates the feasibility of telemedicine across a network of hospitals |
| Hess et al. [11]         | Stroke 2005;36:2018–2020. REACH: clinical feasibility of a rural telestroke network | Descriptive study of a new telestroke web-based consult linking eight rural hospitals with a neurology unit | 194 stroke consults seen with 36 receiving tPA. Onset to treatment time dropped by 32 min during the course of the study | This is an observational study that demonstrates the feasibility of a hub and spoke telestroke system |
| Liman et al. [12]        | Stroke 2012;43:2086–2000. Telestroke ambulances in prehospital stroke management. Concept and pilot feasibility study | To test the technical feasibility of telestroke over a 3G public network to a telemedicine-equipped ambulance with a simulated stroke patient | 18 out of 30 scenarios could not be completed due to poor audiovisual quality. Poor network reliability was identified as a cause of unreliable results | This study highlights the challenges of a mobile telehealth platform using GSM network and demonstrates that it was not technically feasible at least in the location studied |
| Gonzalez et al. [13]     | Stroke 2011;42:1522–1527. Reliability of prehospital real-time cellular video phone in assessing the simplified National Institutes of Health Stroke Scale in patients with acute stroke | Test of reliability of simplified NIHSS scale done remotely (over a cellular videophone on a 3G network) by a physician assisted locally by an emergency medical technician compared with bedside examination by physician | 480 paired comparisons were done. The authors concluded that assessment over videophone was as reliable as bedside and could be a timely method for remote patient assessment | This study analyses the feasibility of conducting NIHSS assessment remotely over a 3G network but does not simulate real-life situation as the participants were not mobile |
| Pedragosa et al. [14]    | Journal of Telemedicine and Telecare               | Retrospective case control of quality of care before and after introduction of telemedicine services | 198 patients were managed with telemedicine compared to 201 cases the year before its introduction. Quality of care improved after introduction of telemedicine with reduction in transfers to stroke centre increased review by neurology specialist | This study compares a telestroke programme with historical control before introduction of this service and requires further studies to confirm their conclusions |
| Demaerschalk et al. [15] | Telemedicine Journal and E-health                  | Pooled analysis of two prospective randomized controlled studies comparing telephone with telemedicine neurological consultation for stroke | 276 pooled patients were evaluated. Telemedicine patients had better outcome with increased tPA treatment and reduced post-tPA bleeding, although 90-day mortality was similar | Although the two studies were identically designed, pooled analysis presents the challenge that the characteristics of the two sampled group may not be identical |
| Nelson et al. [16]       | Neurology 2011;77(17):1590–1598 The cost-effectiveness of telestroke in the treatment of acute ischemic stroke | Cost-effectiveness of telestroke was analysed using a decision analytic model constructed by the team | There are higher upfront cost for telemedicine, but over the lifetime, telestroke is cost-effective | This study focuses only on analysing the cost-effectiveness of telestroke in acute ischaemic stroke and not on other types of stroke. Also, due to lack of published data, some of the conclusions were based on assumptions and estimates |
| Demaerschalk et al. [17] | Stroke 2012;43:3095–3097 CT interpretation in a telestroke network agreement among a spoke radiologist, hub vascular neurologist, and hub neuroradiologist | Randomized double-blind study analysing CT interpretation agreement among spoke radiologist, stroke neurologist, and central radiology adjudication committee | 54 patients were recruited for the study. No significant difference in agreement between telemedicine group and standard method | The patients were randomized, but bias may be introduced by how the choice of telestrokeologist is chosen. Sample size of study is small |
| Wang et al. [18]         | Stroke 2003;34:e188–e191 Remote evaluation of acute ischemic stroke: reliability of National Institutes of Health Stroke Scale via telestroke | Case-control study comparing bedside telemedicine-based NIHSS assessment in stroke patients | 20 patients were recruited for the study. There was no significant difference between bedside and telemedicine-based NIHSS | Small sample size. Larger sample size required to validate the result. Participating physicians not randomized introduce the possibility of bias |
| Study                  | Journal/Year | Description                                                                 | Method/Findings                                                                                                                                                                                                                                                                                                                                 |
|-----------------------|--------------|------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| LaMonte [19]          | Journal of Stroke and Cerebrovascular Diseases 2004;13(4):148–154 | Shortening time to stroke treatment using ambulance telemedicine: TeleBAT | Case-control study comparing the reliability of NIHSS assessment of stroke video images transmitted through telemedicine ambulance (TeleBAT) and TV/VCR. Validity testing indicates that there was no significant difference between TV/VCR and assessment of video transmitted over the telemedicine system. Title indicates study on shortening of time to treatment but study is on analysing the reliability of radiological images transmitted from an ambulance. |
| Handschu et al. [20]   | Stroke 2003;34:2842–2846 | Telemedicine in emergency evaluation of acute stroke: interater agreement in remote video examination with a novel multimedia system | Case-control study comparing bedside with real-time remote video-based NIHSS assessment of stroke patients. 41 patients were recruited for this study. It demonstrated that remote video-based NIHSS assessment was both feasible and comparable to bedside assessment.                                                                                   |
| Puetz et al. [21]     | Neurology 2013;80:332–338 | Reliability of brain CT evaluation by stroke neurologists in telemedicine | Retrospective analysis of the reliability and therapeutic impact of telemedicine-based CT interpretation in stroke patients. CT scans from 536 patients were analysed. There was high inter-observer agreement between telemedicine diagnosis and expert reviewers and minimal impact on clinical outcome.                                                                                                                                 |
| Bergrath et al. [22]  | PLoS ONE 2012;7(5):e36796 | Feasibility of prehospital teleconsultation in acute stroke—a pilot study in clinical routine | A case-control study comparing telemedicine with standard paramedical care in the pre-hospital management of stroke. 18 telemedical and 46 control patients were included in the study. No major effects on clinical processes but improvements in transfer of stroke specific data with corresponding clinical benefits. Study would have been more informative if compared to face-to-face informed consent. |
| Thomas et al. [23]    | Frontiers in Neurology 2012;3:128 | Variability in the perception of informed consent for IV-tPA | Retrospective analysis of the quality of informed consent for IV-tPA. There was very high variability in the perception of consent, but 78.6% rated informed consent as adequate. Study would have been more informative if compared to face-to-face informed consent.                                                                                                                                     |
| Zaidi [24]            | Stroke 2011;42:3291–3293 | Stroke telestroke-guided intravenous tissue-type plasminogen activator treatment achieves a similar clinical outcome as thrombolysis at a comprehensive stroke center | Prospective case-controlled study of telemthal vs. face-to-face management of stroke. Favourable outcome rates were similar between the two groups (42.1% versus 37.5%, P = 0.7). No randomization. Face-to-face patients seen by hub team, while telemedical group seen by the spoke team. |
| Chowdhury et al. [25] | Postgraduate Medical Journal 2012;8:134–137 | Telemedicine versus face-to-face examination in the delivery of thrombolysis for acute ischaemic stroke: a single centre experience | Retrospective case-control study comparing telemedicine with face-to-face management of stroke patient. 97 patients were assessed in the study; 52 (54%) face-to-face and 45 (46%) via telemedicine. Treatment delay was longer in the telemedicine group, but clinical outcome was similar. Method poorly described. Only CT scan appears to be viewed remotely. No information on whether patient assessment was done remotely. No info on how choice was made to use telemedicine. |
| Pervez et al. [26]    | Stroke 2010;41:e18–e24 | Remote supervision of IV-tPA for acute ischemic stroke by telemedicine or telephone before transfer to a regional stroke center is feasible and safe | Retrospective case-control study comparing telemedicine with face-to-face supervision of IV-tPA in the management of stroke patient. 296 patients were included in the study, of which 181 (61.1%) started IV-tPA remotely and 115 (38.9%) under direct supervision. The telestroke group had older patients on the average, but clinical outcomes were similar between both groups. |
| Meyer et al. [27]     | Journal of Stroke and Cerebrovascular Diseases 2012;21(4):259–264 | Assessment of long-term outcomes for the STRoKE DOC telemedicine trial | Retrospective review of the 6-month outcome of telemedicine vs. telephone management. 6-month outcome was not different between the two groups, and mortality was also the same at 18%. |

Amadi-Obi et al. International Journal of Emergency Medicine 2014, 7:29
http://www.intjem.com/content/7/1/29
| Study | Journal | Year | Title | Study Design | Results |
|-------|---------|------|-------|--------------|---------|
| Schwab et al. [28] | Neurology | 2007;69;898–903 | Long-term outcome after thrombolysis in telemedical stroke care | Prospective review of 3- and 6-month clinical outcomes after stroke thrombolysis with telemedicine supervision compared to face-to-face care in a stroke hub | 11.2% mortality of the telemedical group compared to 11.5% in the face-to-face group in first 3 months. Favourable functional outcome was also similar between the two groups. Control group was treated in a stroke centre, while telemedicine group was treated in a community hospital |
| Audebert et al. [29] | Stroke | 2006;37;1822–1827 | Comparison of tissue plasminogen activator administration management between Telestroke Network hospitals and academic stroke centers: the Telemedical Pilot Project for Integrative Stroke Care in Bavaria/Germany | Prospective observational study comparing stroke thrombolysis in regional hospitals remotely supervised over a telemedicine link with thrombolysis in academic stroke unit | 115 patients were treated in the regional hospitals, and 110 were treated in the stroke centres. The rate of IV-APA was higher in stroke centres compared to regional hospitals although the quality of care was similar in both groups. Larger sample size is required to confirm the conclusions in this study |
| Ang et al. [30] | European Journal of Emergency Medicine | 2013;20;5:322–326 | Telestroke: rapid treatment of acute ischemic stroke patients using telemedicine in a Singapore emergency department | Retrospective observational analysis of the use of telemedicine in stroke management in a single centre (spoke). Teleconsultants were neurologist based at a specialist national centre (hub) | 45 patients were enrolled into the telestroke programme, of which 18 were thrombolysed. Limited conclusion was reached due to the descriptive nature of the study. Limited conclusion can be drawn from this study due to the study design and small sample size |
| Switzer [31] | Stroke | 2010;41;566–569 | A telestroke network enhances recruitment into acute stroke clinical trials | Descriptive study analysing whether a hub and spoke telemedicine network enhances recruitment of patients for acute stroke trials | 19 of 28 patients enrolled into two clinical trials were identified at the spoke level. Another nine patients were identified but could not be transported to the hub. This study explores an added advantage of telemedicine as an aid for patient recruitment into clinical studies |
| Agarwal et al. [32] | Journal of the American Heart Association | 2014;3;e000408 | Thrombolysis delivery by a regional telestroke network—experience from the UK National Health service | Observational study to demonstrate the safety and efficacy of out-of-hours telestroke service by a horizontal network of hospitals that have thrombolysis service during working hours. Out-of-hours service was provided by a rota of specialists across the network | A 4-month pilot phase with 15 patients demonstrated safety and feasibility. 164 patients were subsequently recruited over a 12-month period. There was significant increase in the number of thrombolysis carried out with outcomes that are comparable with published studies. This study explores a different model to the traditional ‘hub and spoke’ |
| Richard et al. [33] | Neurological Science | 2014;35;683–685 | Use of telemedicine to manage severe ischaemic strokes in a rural area with an elderly population | Observational study analysing the effectiveness and safety of a telestroke programme in a rural area with a high elderly population | 53 patients were recruited to the study over 16-month period. Outcome was worse than those in the published studies but the average age of this study group is much higher than those in other published data. Sample size is small, and study design does not allow clear conclusions from the study |
| Demaerschalk et al. [34] | Stroke | 2012;43;3098–3101 | Smartphone teleradiology application is successfully incorporated into a telestroke network environment | Case-control study assessing the reliability of smartphone-based CT interpretation by comparing it with PACS-based system | 53 patients were recruited. There was an agreement (95% CI) between smartphone-based and PACS-based systems, suggesting that smartphone based systems are a reliable alternative. This study compares the interpretation by neurologists on smartphone with radiologists on PACS system, introducing a possible bias based on different specialties. Like-for-like comparison may be required to validate their study |
| Authors          | Journal/title                                                                 | Methodology                                                                 | Summary of findings                                                                 | Comments                                                                 |
|------------------|--------------------------------------------------------------------------------|----------------------------------------------------------------------------|-------------------------------------------------------------------------------------|--------------------------------------------------------------------------|
| Terkelsen et al. [35] | European Heart Journal 2005;26(8):770–777 Reduction of treatment delay in patients with ST-elevation myocardial infarction: impact of pre-hospital diagnosis and direct referral to primary percutaneous coronary intervention | Comparative analysis of treatment delay in patients diagnosed with ST-segment elevated myocardial infarction (STEMI) during the pre-hospital period or in hospital | Treatment delay was significantly reduced in patients diagnosed during the pre-hospital period |                                                                       |
| Zanini et al. [36] | Journal of Cardiovascular Medicine 2008;570–575 Impact of prehospital diagnosis in the management of ST elevation myocardial infarction in the era of primary percutaneous coronary intervention: reduction of treatment delay and mortality | Observational study comparing STEMI patients transported with telemedicine-supported ambulance with patient diagnosed in hospital | 399 patients were recruited: 136 via telemedicine, while 263 came directly to the hospital. There was significant reduction treatment delay in the telemedicine compared to the in-hospital group | This is an observational study. Randomized controlled study will be required to validate the results |
| Brunetti [37] | European Journal of Cardiovascular Prevention & Rehabilitation 2010;17:615 Telecardiology improves quality of diagnosis and reduces delay to treatment in elderly patients with acute myocardial infarction and atypical presentation | Observational study to analyse the effectiveness of telemedicine in the diagnosis of STEMI | Of the 27,841 patients recruited for the study, 534 had ECG changes consistent with STEMI. Telemedicine improved the quality of diagnosis of STEMI and also led to reduction in treatment delay | Large prospective study with statistically significant conclusions |
| Terkelsen et al. [38] | Journal of Internal Medicine 2002;252:412–420 Telemedicine used for remote prehospital diagnosing in patients suspected of acute myocardial infarction | Observational study analysing the technical feasibility of diagnosis of myocardial infarction from ECG transmitted from an ambulance over a GSM network | Of the 250 patients with ECG transmitted, 214 (86%) were technically successful. Telemedicine also reduced treatment delays | This study compared telemedicine-equipped ambulance with regular ambulance. No selection mechanism was used to decide which ambulance transport a patient |
| Sejersten et al. [39] | American Journal of Cardiology 2007;110:38 Effect on treatment delay of prehospital teletransmission of 12-lead electrocardiogram to a cardiologist for immediate triage and direct referral of patients with ST-segment elevation acute myocardial infarction to primary percutaneous coronary intervention | Case-control study to determine whether treatment delays in myocardial infarction can be reduced by transmitting pre-hospital 12-lead ECG directly to cardiologist phone | Of the 243 patients enrolled in the study, 184 were referred for percutaneous coronary intervention (PCI). ECG transmission was successful in 94%. 72% of the telemedicine group underwent PCI within 90 min of 911 call compared to 13% in the historical controls | Historical controls were used for the study, indicating the possibility of bias |
| Authors            | Journal/title                                      | Methodology                              | Summary of findings                                                                                      | Comment                                                                 |
|--------------------|----------------------------------------------------|------------------------------------------|----------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------|
| Duchesne et al.    | *The Journal of Trauma* 2008;64(1):92–97           | Comparative analysis of the outcomes     | Telemedicine improved trauma evaluation and management and led to reduction in hospital cost and mortality | The use of historical controls in this study introduces bias that compromises the conclusions of the study |
| Saffle et al.      | *The Journal of Trauma* 2009;67(2):358–365         | Retrospective comparative analysis of    | 80 patients were recruited to the telemedicine arm, while 28 were recruited during the same period pre-telemedicine. Burns assessment by telemedicine is both accurate and low cost | This study uses historical controls in its analysis. Its conclusion will require conformation by a large randomized control study |
| Boniface et al.    | *American Journal of Emergency Medicine* 2007;29:477–481 | Analysed whether paramedics could        | 51 paramedics were able to complete FAST with 100% of the view under emergency physician guidance          | This is an observational study that demonstrates the feasibility of telemedicine-guided FAST by novice paramedics. Further studies will be needed to explore its accuracy |
| Charash et al.     | *Journal of Trauma* 2011;71(1):49–54               | Prospective double-blind study of simulated trauma patients. The study compares the outcomes of trauma care in a moving ambulance between telemedicine group and non-telemedicine control | Telemedicine to a moving ambulance improves care and successfully guide EMs through needle thoracostomy and pericardiocentesis | This is a well-designed simulation study that will require investigation with real-life scenarios to confirm their findings |
| Rogers et al.      | *The Journal of Trauma Injury, Infection, and Critical Care* 2003;51:1037–1041 | Observational study analysing whether real-time telemedicine consult with a trauma surgeon by community hospital emergency department positively affects care | 26 teleconsults were carried out by trauma surgeons over an 8-month period, and survey indicated that 83% felt telemedicine improved patient care | This study is descriptive, and no conclusions were reached |
| Wallace et al.     | *Journal of Telemedicine and Telecare* 2007;13:282–287 | Prospective cohort study comparing the management of patients referred to a burns unit with/without telemedicine | Telemedicine group was more likely to be booked directly to day surgery without the need for initial assessment. Of the 34 responders to the survey, 31 thought telemedicine improved patient care | The authors did not specify the method of selection of which facilities had telemedicine units installed. There is also very limited description of the facilities, making comparison very difficult |
| Tachakra et al.    | *Journal of Telemedicine and Telecare* 2011;17:350–357 | Case-control study comparing the diagnostic accuracy of telemedicine with face-to-face in minor trauma | 200 patients were recruited for the study. There was a very high diagnostic accuracy both in the final diagnosis and in the clinical features | Physicians involved were not blinded or randomized |
| Rörtgen et al.     | *Resuscitation* 2013;84(1):85–92                   | Randomized controlled study comparing emergency physician team with telemedicine-assisted paramedic teams in management of four simulated clinical scenario | Total of 31 scenarios were completed by both groups, and there was no statistical difference between the groups’ performance | Well-designed study that demonstrates feasibility and quality in a simulation |
| Tachakra et al.    | *Journal of Telemedicine and Telecare* 2009;6:330–334 | Retrospective review of patients in a minor trauma telemedicine programme for diagnostic accuracy and sequelae of initial trauma | Diagnosis was wrong in 2% of patients that were managed with telemedicine. The results were similar with those of face-to-face | Observational study |
referral in an acute burns unit led to a reduction in admission that could reduce hospital costs [45].

**Myocardial infarction**

The ideal recommendation for reperfusion of STEMI is within 2 h of first medical contact [58]. The requirement for urgent management of patients with myocardial infarction can be facilitated by the use of telemedicine for diagnosis and treatment. Efforts to shorten treatment delay are crucial, and various studies have been published addressing this challenge. Patient transfer directly to percutaneous coronary intervention (PCI) laboratory after pre-hospital diagnosis of STEMI in a telemedicine-equipped ambulance reduced treatment delay [35,36] and reduced mortality from myocardial infarction [59]. To expedite reduction in treatment delay, accurate ECG diagnosis of STEMI remains crucial. Currently computer [60] and paramedics [7] ECG interpretation are not reliable enough to enhance patient triage for urgent PCI.

**Conclusion**

This review found limited conclusive studies for the effectiveness of telemedicine in emergency medicine. The best evidence is in stroke management where conclusive evidence of the significant positive effect of telesstroke on clinical outcome has led to its recommendation for stroke management. Telemedicine appears to have a significant impact on the quality of ECG interpretation, but there is as yet no conclusive evidence that telemedicine affects clinical outcome in myocardial infarction. We could find very few studies that critically analysed telemedicine use in the pre-hospital care of trauma. Studies have demonstrated that burns assessment using telemedicine was as accurate as face-to-face assessment.

The proliferation of smartphones, tablets, and other mobile electronic devices creates an opportunity to extend standard professional health care particularly in medical emergencies where urgent intervention could reduce mortality and improve quality of life. Telemedicine could enhance emergency medical services by helping expedite urgent patient transfer, improve remote consultation, and enhance supervision of paramedics and nurses.

However, in order to regulate and standardize practice, more research is required. Particular emphasis should be on better study design and larger sample size to improve the reliability of results and conclusions. A large proportion of the studies analysed focused on ambulance mounted equipment. Wearable technology such as head-mounted displays that will allow paramedics reach patients in situ may improve early pre-hospital diagnosis and should be investigated. To further reduce response times, consideration should also be given to incorporating smartphone technology into emergency systems and thus facilitate patient or bystander incident reporting. Although technological advances will continue to outpace their utilization in clinical practice, incorporating emerging technologies into medical practice holds promise in improving care and enhancing clinical outcomes, and researchers must continue to evaluate the effectiveness of telemedicine so that communication technology-assisted care is optimized.

**Competing interests**

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**Authors’ contributions**

Conception and design of the review was done by AA, PG, and NO. Articles were independently reviewed by AA and NO. PG provided study oversight. All authors participated in the critical review and revision of manuscripts. All authors read and approved the final manuscript.

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