Review article

Systematic review of telemedicine applications in emergency rooms

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Abstract

Context: Despite the frequency of use of telemedicine in emergency care, limited evidence exists on its impacts at the patient, provider, organization, and system level. Hospital-based applications of telemedicine present a potentially important solution, particularly for small and rural hospitals where access to local specialists is rarely available.

Purpose: We conducted a systematic review of telemedicine applications for hospital-based emergency care, which aims to synthesize the existing evidence on the impact of tele-emergency applications that could inform future efforts and research in this area.

Basic procedures: A search of four databases (PubMed, CINAHL, EMBASE, Cochrane) using a combination of telemedicine and emergency room (ER) keywords for publications yielded 340 citations. Four coders independently determined eligibility based on initial criteria and then extracted information on the 38 resulting articles based on four main categories: study setting, type of technology, research methods, and results.

Main findings: Of the 38 articles, 11 studies focused on telemedicine for diffuse patient populations that typically present in ERs, 8 studies considered telemedicine in the context of minor treatment clinics for patients presenting with minor injuries or illnesses, and 19 studies focused on the use of telemedicine to connect providers in ERs to medical specialists for consultations on patients with specific conditions. Overwhelmingly, tele-emergency studies reported positive findings especially in terms of technical quality and user satisfaction. There were also positive findings reported for clinical processes and outcomes, throughput, and disposition, but the rigor of studies using these measures was limited. Studies of economic outcomes are particularly sparse.

Principal conclusions: Despite limitations in their research methodology, the studies on tele-emergency indicate an application with promise to meet the needs of small and rural hospitals to address infrequent but emergency situations requiring specialist care. Similarly, studies indicate that tele-emergency has considerable potential to expand use of minor treatment clinics to address access issues in remote areas and overcrowding of urban ERs.

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1. Introduction

Definitions of telemedicine by the Institute of Medicine (IOM), World Health Organization, and American Telemedicine Association [1–3] vary somewhat, but the core of most definitions is “the delivery of health care services at a distance, using information and communication technology”, where information and communication technology encompasses a broad range of potential applications [4]. Many telemedicine applications connect patients directly to providers. Other applications focus on clinicians but employ asynchronous communication only, or largely use videoconferencing for educational purposes. An extremely important area of telemedicine connects clinicians during an acute episode of patient care, usually linking small, rural hospital settings that have limited resources to larger, urban medical centers. Telemedicine applications in emergency rooms (tele-emergency) are a prime example. In a recent analysis of the 2011 Health Information and Management Systems Society (HIMSS) Analytics dataset [5], which aimed at deriving national estimates of hospital-based telemedicine use, we found that two of the three most frequently used services were in emergency/trauma care departments and in cardiology/stroke/heart attack programs [6].

Despite this reported frequency of use of telemedicine in emergency care, limited evidence exists on its impacts at various levels related to the technical quality, users’ perceptions, clinical processes and outcomes, disposition and throughput of patients, and economic effects. Hospital-based applications of telemedicine appear to present a potentially important solution, particularly for small and rural hospitals where access to local specialists is rarely available [7]. Yet, a PubMed search for meta-analyses and systematic reviews on telemedicine and telehealth yielded 55 citations, of which only three are specifically hospital-based applications other than those covering tele-ICU [12] were found. Thus, in view of the relatively frequent use of telemedicine in emergency/trauma care departments and cardiology/stroke/heart attack programs, we undertook a systematic review of the empirical studies of telemedicine applications for hospital-based emergency care to synthesize the existing evidence on the impact of tele-emergency applications, which could inform future efforts and research in this area. This paper presents a systematic review of published research evidence on tele-emergency applications, which synthesizes existing evidence and identifies knowledge gaps in this area. It further provides stakeholders, researchers, and funding agencies with knowledge that focuses attention on priority areas for future investigation, as well as highlights various evidence-based interventions of telemedicine applications in emergency room settings.

2. Materials and methods

According to Moher et al., a systematic review represents a type of literature review that employs systematic and explicit methods for the identification, selection, and critical appraisal of relevant research in a specific field [13]. It summarizes the results of the empirical studies qualitatively, in a narrative approach, in order to present information on the direction, size, strength of evidence, and consistency of the “effect” across the included studies [14]. Unlike a critical review, which usually involves a selective or representative search of existing literature and focuses on critical assessment and explanations, a systematic review adopts a comprehensive search/inclusion of empirical studies and integrates and synthesizes existing literature in a specific domain [14].

The PRISMA guidelines [13] and existing systematic review articles identified the most commonly used databases for a comprehensive search of the literature on this topic as PubMed, CINAHL, EMBASE, and the Cochrane Database. “Telemedicine” and “telehealth” are often used interchangeably, as such, both were used as search terms. Thus, the
search in this review was conducted using the following combinations of terms: (1) “telemedicine AND emergency room”; OR (2) “telehealth AND emergency room”; OR (3) “tele AND emergency room”. Searches were conducted for all articles published before September 2013. These searches yielded 340 non-duplicative citations. Of these, 18 citations were excluded because they were in a non-English language or full articles were not available after multiple attempts to locate full text versions, including requests through inter-library loan.

For the first review step, four coders independently examined the remaining 322 articles. Each coder determined whether or not the article met each of three inclusion/exclusion criteria, which consisted of: (1) telehealth/telemedicine topic; (2) emergency room (ER) setting; and (3) empirical study presenting results on the effects/impacts of telemedicine in the context studied. On the topic of telehealth/telemedicine, the IOM definition of telemedicine was used to include articles that were on the topic of telehealth/telemedicine and to exclude articles that were not on that topic. The IOM definition is “the use of electronic information and communications technologies [including audio, video, and other] to provide and support health care when distance separates the participants” [1]. In addition, the study must focus on an ER telemedicine application to be included in the systematic review. Finally, the article must be based on an empirical study or evaluation study of a tele-emergency application to be included in the systematic review. The definition used was “the study, based on direct observation, use of statistical records, interviews, or experimental methods, of actual practices or the actual impact of practices or policies” [15]. Conceptual articles, discussions, editorials, letters, abstracts, or nonempirical dissertations were excluded, as were single-case studies. Since this is the first review of telemedicine studies that is focused on hospital-based emergency care, we aimed to keep the review as inclusive as possible and thus we did not eliminate any article based on methodological rigor. This step in the process eliminated 228 articles, which left 94 articles that were retained for data extraction.

For the next level of review, a list of data elements capturing the article content was compiled. Telehealth/telemedicine applications are diverse, as reflected in two recent taxonomies that categorize these applications along multiple dimensions [16,17]. Applying these taxonomies to tele-emergency studies, we developed a classification scheme, which included four main categories to code the information extracted from the empirical studies: (1) Study setting provided information related to the patient population, clinical setting, communication parties, country of study, and number of facilities involved; (2) Type of technology reflected the nature of the technology used in the telemedicine encounter; (3) Research methods covered the study design, study timing, study duration, level of evidence, inclusion of a control group, and number of patients or consultations; and (4) Results included the scope of service for telemedicine, measures recorded, whether statistical analyses were conducted, and positive/negative conclusion reached. Definitions and response options for each category were developed (Attachment A). Four coders independently examined each article. During the course of coding data elements, further reading of the articles identified 21 that were not specifically evaluations of tele-emergency applications and 6 that only covered transmitting signals from emergency vehicles to the ER. These articles were excluded. It also became apparent that 29 of the articles could be classified as “feasibility only” studies, which involved examining the feasibility of the use of the technology itself. Because the data collected and results reported were limited to ratings of image acceptability and because the technology was still in the testing phase and not being used in regular practice, we classified these as feasibility studies and excluded them. Otherwise, the remaining 38 evaluations of tele-emergency applications were included, regardless of the study setting, type of technology, or research methods reported. Fig. 1 shows a flow chart of the articles included at each step of the review process.

3. Results

3.1. Overview of study characteristics

A total of 38 articles presented data from evaluations of tele-emergency applications in real-world clinical settings. A close examination of these articles revealed clustering of the studies into three major types, which represent different contexts of tele-emergency applications. Full references for these studies are listed in Table 1, and grouped by the three types of tele-emergency applications described below. Within each group, the references are ordered by date from oldest to newest, and alphabetically when multiple studies were published in the same year.

For the first group, 11 studies focused on the use of telemedicine for diffuse patient populations that typically present in ERs, and were classified as “General ER Use” (GEN). For the second group, eight studies considered telemedicine in the context of minor treatment clinics for patients presenting with minor injuries or illnesses, and were classified as “MTC”. For the third group, 19 studies focused on the use of telemedicine to connect providers in ERs to medical specialists for consultations on patients with specific conditions and were classified as “Special Patient Populations” (SPP). Among the 19 studies in the SPP group, the patient populations varied including individuals suffering from stroke symptoms (26%), trauma (21%), ophthalmology conditions (16%), cardiac problems (11%), and other conditions (e.g., dermatology, psychiatric, respiratory). Table 2 shows key characteristics of the 38 tele-emergency studies that were included in this review.

All eight MTC studies were conducted in the U.K. In the GEN and SPP groups of 30 studies, more than half were conducted in the U.S. (17 studies), a fifth were conducted in the U.K. (six studies), and the remaining (seven studies) originated from Australia, Canada, South Korea, and Taiwan.

The scope of service provided through tele-emergency varied across studies. In 13 studies (34%), telemedicine was used for teleconsultation only. Another set of 15 studies (39%) incorporated some aspect of telepresence (i.e. situations where the physician who is connected through the system had direct involvement in the care provided to the patient and/or directly interacted with him/her), and eight studies (21%) included tele-radiology. The SPP studies frequently used a combination of
Table 1 – References of articles included in systematic review.

22. J.A. Töppi, K.S. Lee, Dobutamine stress tele-echocardiography as a clinical service in the emergency department to evaluate patients with chest pain, Echocardiography. 16 (2) (1999) 179–185  
specialized services, often involving teleconsultation or tele-presence along with tele-stroke (five studies), tele-trauma (four studies), tele-ophthalmology (three studies), tele-dermatology (one study), or tele-airway management (one study). The specialized telemedicine applications always connected the ER personnel to a specialist and sometimes employed advanced equipment (e.g., special cameras to view the eye or skin).

In terms of settings, all except for one study (connecting a correctional facility to an ER) linked health care facilities with one end of the connection residing in an ER. Seven studies (18%) used the technology within a single hospital (often from the ER to a clinic-based specialist), 13 studies (34%) used telemedicine to connect ERs in two separate hospitals, and the remaining 17 studies

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**Table 1 – (Continued)**

<table>
<thead>
<tr>
<th>Record identified through PubMed (n=86)</th>
<th>Record identified through CINAHL (n=77)</th>
<th>Record identified through Cochrane Collaborative (n=74)</th>
<th>Record identified through EMBASE (n=103)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of records identified through database searching (n=340)</td>
<td>Number of full-text articles not available, conference proceedings, or non-English articles (n=18)</td>
<td>Number of full-text articles screened for eligibility (n=322)</td>
<td>Number of articles excluded for not meeting the initial eligibility criteria (n=228)</td>
</tr>
<tr>
<td>Number of studies with data on tele-ER implementation (n=94)</td>
<td>Number of articles not fitting criteria as evaluation of tele-ER (n=27)</td>
<td>Number of studies included in data synthesis coding (n=38)</td>
<td>Number of articles only on feasibility of tele-ER technology (n=29)</td>
</tr>
</tbody>
</table>

**Fig. 1 – PRISMA flow diagram of included studies.**
Table 2 – Descriptive overview of tele-emergency study characteristics.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Country</th>
<th>Type of patients</th>
<th>Settings</th>
<th>Communicating clinicians</th>
<th>Scope of service</th>
<th>Technology used</th>
<th>Study design (level)</th>
<th>Size of experimental (E) and control (C) groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>Armstrong &amp; Haston (1997)</td>
<td>UK</td>
<td>Mostly minor trauma</td>
<td>1 ER to 1 ER</td>
<td>Physician to Physician</td>
<td>Teleconsultation, Telepresence, Teleradiology</td>
<td>Real time audio/visual and image transfer</td>
<td>Prospective non-randomized pre-post with no control (III-3)</td>
<td>E = 120 C = N/A consultations</td>
</tr>
<tr>
<td>Brennan et al. (1998)</td>
<td>USA</td>
<td>Diffuse Patient Population</td>
<td>1 ER to 1 ER</td>
<td>Nurse to Physician</td>
<td>Teleconsultation, Telepresence</td>
<td>Real time audio/visual and image transfer</td>
<td>Randomized with no-treatment control (II)</td>
<td>E = 54 C = 50 patients</td>
</tr>
<tr>
<td>Kofos et al. (1998)</td>
<td>USA</td>
<td>Pediatric</td>
<td>Within 1 Hospital</td>
<td>Physician to Physician</td>
<td>Teleconsultation</td>
<td>Real time audio/visual</td>
<td>Prospective case series with post-test only (IV)</td>
<td>E = 15 C = N/A patients</td>
</tr>
<tr>
<td>Brennan et al. (1999)</td>
<td>USA</td>
<td>Non-emergent Diffuse Patient Population</td>
<td>1 ER to 1 ER</td>
<td>Nurse to Physician</td>
<td>Teleconsultation, Telepresence</td>
<td>Real time audio/visual</td>
<td>Randomized with no-treatment control (II)</td>
<td>E = 54 C = 50 patients</td>
</tr>
<tr>
<td>Chi et al. (1999)</td>
<td>Taiwan</td>
<td>Diffuse Patient Population</td>
<td>1 ER to 1 ER</td>
<td>Physician to Physician</td>
<td>Teleconsultation, Teleradiology</td>
<td>Real time audio/visual and image transfer</td>
<td>Prospective non-randomized pre-post with no control (III-3)</td>
<td>E = 275 C = N/A consultations</td>
</tr>
<tr>
<td>Stamford et al. (1999)</td>
<td>USA</td>
<td>Diffuse Patient Population</td>
<td>1 ER to 1 ER</td>
<td>Physician to Physician</td>
<td>Teleconsultation, Teleradiology</td>
<td>Real time audio/visual and image transfer</td>
<td>Retrospective case series with post-test only (IV)</td>
<td>E = 118 C = N/A patients</td>
</tr>
<tr>
<td>Brebner et al. (2002)</td>
<td>UK</td>
<td>Diffuse Patient Population</td>
<td>4 ERs to 1 ER</td>
<td>Physician or Nurse to Physician</td>
<td>Teleconsultation, Teleradiology</td>
<td>Real time audio/visual and image transfer</td>
<td>Prospective non-randomized pre-post with no control (III-3)</td>
<td>E = 402 C = N/A consultations</td>
</tr>
<tr>
<td>Ferguson et al. (2003)</td>
<td>UK</td>
<td>Mostly minor trauma</td>
<td>14 ERs to 1 ER</td>
<td>Physician or Nurse Practitioner to Physician</td>
<td>Teleconsultation</td>
<td>Real time audio/visual</td>
<td>Prospective non-randomized pre-post with no control (III-3)</td>
<td>E = 407 C = N/A consultations</td>
</tr>
<tr>
<td>Study</td>
<td>Location</td>
<td>Population Type</td>
<td>Setting</td>
<td>Specialist to Specialist Distance</td>
<td>Communication Method</td>
<td>Study Design</td>
<td>outcomes</td>
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</tr>
<tr>
<td>Ellis et al. (2006)</td>
<td>USA</td>
<td>Diffuse Patient Population</td>
<td>51 Correctional facilities to 1ER</td>
<td>Staff to Physician or Nurse Pract/Phys Assist Nurse Practitioner to Physician</td>
<td>Teleconsultation</td>
<td>Real time audio/visual</td>
<td>Retrospective case series with post-test only (IV)</td>
<td>E = 1,522 C = N/A consultations</td>
</tr>
<tr>
<td>Galli et al. (2008)</td>
<td>USA</td>
<td>Diffuse Patient Population</td>
<td>11 ERs to 1 ER</td>
<td>Nurse Practitioner to Physician</td>
<td>Teleconsultation</td>
<td>Real time audio/visual</td>
<td>Prospective case series with post-test only (IV)</td>
<td>E = 26,697 C = N/A patients</td>
</tr>
<tr>
<td>Heaney et al. (2009)</td>
<td>UK</td>
<td>Non-emergent Diffuse Patient Population</td>
<td>Within 1 Hospital</td>
<td>Patient to Physician</td>
<td>Telepresence</td>
<td>Real time audio/visual</td>
<td>Prospective case series with post-test only (IV)</td>
<td>E = 105 C = N/A patients</td>
</tr>
<tr>
<td>Minor treatment clinics (MTC)</td>
<td></td>
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<td></td>
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<td>Retrospective case series with post-test only (IV)</td>
<td>E = 51 C = N/A patients</td>
</tr>
<tr>
<td>Darkins et al. (1996)</td>
<td>UK</td>
<td>Diffuse Patient Population</td>
<td>1 Minor Treatment Clinic to 1 ER</td>
<td>Nurse Practitioner to Physician</td>
<td>Teleconsultation, Teleradiology</td>
<td>Real time audio/visual</td>
<td>Retrospective case series with post-test only (IV)</td>
<td>E = 51 C = N/A patients</td>
</tr>
<tr>
<td>Beach et al. (2000)</td>
<td>UK</td>
<td>Minor injuries</td>
<td>2 Minor Treatment Clinics to 1 ER</td>
<td>Clinical Staff to Physician</td>
<td>Teleconsultation, Teleradiology</td>
<td>Real time audio/visual and image transfer</td>
<td>Prospective case series with post-test only (IV)</td>
<td>E = 71 C = N/A patients</td>
</tr>
<tr>
<td>Salmon et al. (2000)</td>
<td>UK</td>
<td>Minor injuries</td>
<td>2 Minor Treatment Clinics to 1 ER</td>
<td>Nurse Practitioner to Physician</td>
<td>Teleconsultation</td>
<td>Real time audio/visual and image transfer</td>
<td>Prospective case series with post-test only (IV)</td>
<td>E = Not specified C = N/A patients</td>
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<td>Wootton et al. (2000)</td>
<td>UK</td>
<td>Minor injuries</td>
<td>15 Minor Treatment Clinics to 1 ER</td>
<td>Nurse to Physician</td>
<td>Teleconsultation</td>
<td>Real time audio/visual and image transfer</td>
<td>Prospective case series with post-test only (IV)</td>
<td>E = 91 C = N/A patients</td>
</tr>
<tr>
<td>Tachakra et al. (2001)</td>
<td>UK</td>
<td>Minor injuries</td>
<td>1 Minor Treatment Clinic to 1 ER</td>
<td>Nurse Practitioner to Physician</td>
<td>Teleconsultation, Teleradiology</td>
<td>Real time audio/visual and image transfer</td>
<td>Prospective case series with post-test only (IV)</td>
<td>E = 200 C = N/A consultations</td>
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<td>Noble et al. (2005)</td>
<td>UK</td>
<td>Minor Injuries</td>
<td>Within 1 Hospital</td>
<td>Nurse to Physician</td>
<td>Teleconsultation</td>
<td>Real time audio/visual and image transfer</td>
<td>Randomized with no-treatment control (II)</td>
<td>E = 191 C = 62) patients</td>
</tr>
<tr>
<td>Reference</td>
<td>Country</td>
<td>Type of patients</td>
<td>Settings</td>
<td>Communicating clinicians</td>
<td>Scope of service</td>
<td>Technology used</td>
<td>Study design (level)</td>
<td>Size of experimental (E) and control (C) groups</td>
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<tr>
<td>Mair &amp; Ferguson (2008)</td>
<td>UK</td>
<td>Minor injuries</td>
<td>3 Minor Treatment Clinics to 1 ER</td>
<td>Nurse to Physician</td>
<td>Teleconsultation</td>
<td>Real time audio/visual and image transfer</td>
<td>Retrospective</td>
<td>E = 112 C = N/A patients</td>
</tr>
<tr>
<td>Miller et al. (2008)</td>
<td>UK</td>
<td>Minor injuries</td>
<td>15 Minor Treatment Clinics to 1 ER</td>
<td>Nurse Practitioner to Physician</td>
<td>Teleconsultation</td>
<td>Real time audio/visual</td>
<td>Retrospective</td>
<td>E = 835 C = N/A patients</td>
</tr>
<tr>
<td>Blackwell et al. (1997)</td>
<td>Australia</td>
<td>Ophthalmic</td>
<td>1 ER to 1 Specialist</td>
<td>Physician to Specialist</td>
<td>Tele-ophthalmology Consultation,</td>
<td>Real time audio/visual</td>
<td>Non-randomized design with a historical comparison group (III-3)</td>
<td>E = 264 C = 315 patients</td>
</tr>
<tr>
<td>Rosengren et al. (1998)</td>
<td>Australia</td>
<td>Ophthalmic</td>
<td>1 ER to 1 Specialist</td>
<td>Physician to Specialist</td>
<td>Tele-ophthalmology Consultation</td>
<td>Real time audio/visual</td>
<td>Retrospective</td>
<td>E = 24 C = N/A patients</td>
</tr>
<tr>
<td>Trippi &amp; Lee (1999)</td>
<td>USA</td>
<td>Cardiology</td>
<td>Within 1 Hospital</td>
<td>Nurse or Sonographer to Specialist</td>
<td>Teleconsultation</td>
<td>Telephone image transfer</td>
<td>Retrospective</td>
<td>E = 734 C = N/A patients</td>
</tr>
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<td>Rogers et al. (2001)</td>
<td>USA</td>
<td>Trauma</td>
<td>4 ERs to 1 Specialist</td>
<td>Physician to Specialist</td>
<td>Tele-trauma Consultation, Telepresence</td>
<td>Real time audio/visual</td>
<td>Prospective non-randomized with concurrent control (III-2)</td>
<td>E = 26 C = 816 patients</td>
</tr>
<tr>
<td>Bowman et al. (2003)</td>
<td>UK</td>
<td>Ophthalmic</td>
<td>Within 1 Hospital</td>
<td>Nurse to Specialist</td>
<td>Tele-ophthalmology Consultation,</td>
<td>Real time audio/visual</td>
<td>Prospective non-randomized with concurrent control (III-2)</td>
<td>E = 40 C = 40 patients</td>
</tr>
<tr>
<td>LaMonte et al. (2003)</td>
<td>USA</td>
<td>Stroke</td>
<td>1 ER to 1 Specialist</td>
<td>Physician to Specialist</td>
<td>Tele-stroke Consultation, Telepresence</td>
<td>Real time audio/visual and image transfer</td>
<td>Retrospective</td>
<td>E = 23 C = N/A consultations</td>
</tr>
<tr>
<td>Study</td>
<td>Location</td>
<td>Speciality</td>
<td>Setting</td>
<td>Service Type</td>
<td>Communication</td>
<td>Design</td>
<td>E</td>
<td>C</td>
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<tr>
<td>Ricci et al. (2003)</td>
<td>USA</td>
<td>Trauma</td>
<td>4 ERs to 1 Specialist</td>
<td>Tele-trauma Consultation, Telepresence</td>
<td>Real time audio/visual</td>
<td>Prospective non-randomized with concurrent control (III-2)</td>
<td>24</td>
<td>483 patients</td>
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<tr>
<td>Scheinfeld et al. (2003)</td>
<td>USA</td>
<td>Dermatology</td>
<td>Within 1 Hospital</td>
<td>Tele-dermatology Consultation</td>
<td>Real time audio/visual and image transfer</td>
<td>Prospective case series with post-test only (IV)</td>
<td>51</td>
<td>N/A patients</td>
</tr>
<tr>
<td>Archbold et al. (2004)</td>
<td>UK</td>
<td>Trauma</td>
<td>3 ERs to 1 Specialist</td>
<td>Tele-trauma Consultation, Teleradiology</td>
<td>Image transfer Mobile Phone via MMS</td>
<td>Prospective case series with post-test only (IV)</td>
<td>46</td>
<td>N/A consults</td>
</tr>
<tr>
<td>Schwamm et al. (2004)</td>
<td>USA</td>
<td>Stroke</td>
<td>1 ER to 1 Specialist</td>
<td>Tele-stroke Consultation, Telepresence</td>
<td>Real time audio/visual and image transfer Telephone image transfer</td>
<td>Retrospective case series with post-test only (IV)</td>
<td>24</td>
<td>N/A patients</td>
</tr>
<tr>
<td>Tsai et al. (2004)</td>
<td>Taiwan</td>
<td>Extremity Wounds</td>
<td>1 ER to 1 Specialist</td>
<td>Teleconsultation</td>
<td>Real time audio/visual and image transfer</td>
<td>Prospective case series with post-test only (IV)</td>
<td>60</td>
<td>N/A patients</td>
</tr>
<tr>
<td>Duchesne et al. (2008)</td>
<td>USA</td>
<td>Trauma</td>
<td>7 ERs to 1 ER Nurse Practitioner to Physician</td>
<td>Tele-trauma Consultation, Telepresence</td>
<td>Real time audio/visual and image transfer</td>
<td>Non-randomized design with a historical comparison group (III-3)</td>
<td>351</td>
<td>463 patients</td>
</tr>
<tr>
<td>Meyer et al. (2008)</td>
<td>USA</td>
<td>Stroke</td>
<td>4 ERs to 1 Specialist</td>
<td>Tele-stroke Consultation, Telepresence</td>
<td>Real time audio/visual and image transfer</td>
<td>Randomized with no-treatment control (II)</td>
<td>111</td>
<td>111 patients</td>
</tr>
<tr>
<td>Saffle et al. (2008)</td>
<td>USA</td>
<td>Burn Injuries</td>
<td>3 EDs to 1 Specialist</td>
<td>Teleconsultation</td>
<td>Real time audio/visual</td>
<td>Non-randomized design with a historical comparison group (III-3)</td>
<td>80</td>
<td>28 patients</td>
</tr>
<tr>
<td>Reference</td>
<td>Country</td>
<td>Type of patients</td>
<td>Settings</td>
<td>Communicating clinicians</td>
<td>Scope of service</td>
<td>Technology used</td>
<td>Study design (level)</td>
<td>Size of experimental (E) and control (C) groups</td>
</tr>
<tr>
<td>--------------------</td>
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<tr>
<td>Switzer et al.</td>
<td>USA</td>
<td>Stroke</td>
<td>9 EDs to 1 Specialist</td>
<td>Physician to Specialist</td>
<td>Tele-stroke Consultation, Telepresence</td>
<td>Real time audio/visual and image transfer</td>
<td>Prospective non-randomized with concurrent control (III-2)</td>
<td>E = 49 C = 26 patients</td>
</tr>
<tr>
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</tr>
<tr>
<td>Demaerschalk et al.</td>
<td>USA</td>
<td>Stroke</td>
<td>not specified</td>
<td>Physician to Nurse Practitioner Specialist</td>
<td>Tele-stroke Consultation, Telepresence</td>
<td>Real time audio/visual and image transfer</td>
<td>Prospective case series with post-test only (IV)</td>
<td>E = 10 C = N/A patients</td>
</tr>
<tr>
<td>(2010)</td>
<td></td>
<td></td>
<td></td>
<td>Patient/Nurse to Nurse Specialist</td>
<td>Teleconsultation, Telepresence</td>
<td>Real time audio/visual</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bhandari et al.</td>
<td>Canada</td>
<td>Psychiatric</td>
<td>2 EDs to 1 Specialist</td>
<td>Physician to Specialist</td>
<td>Tele-stroke Consultation, Telepresence</td>
<td>Real time audio/visual and image transfer</td>
<td>Prospective case series with post-test only (IV)</td>
<td>E = 13 C = N/A patients</td>
</tr>
<tr>
<td>(2011)</td>
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<td></td>
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<tr>
<td>Chen et al. (2011)</td>
<td>Taiwan</td>
<td>Cardiology</td>
<td>Within 1 Hospital</td>
<td>Nurse to Specialist</td>
<td>Teleconsultation</td>
<td>E-mail, Mobile Phone image transfer</td>
<td>Non-randomized design with a historical comparison group (III-3)</td>
<td>E = 51 C = 54 patients</td>
</tr>
<tr>
<td>Cho et al. (2011)</td>
<td>S. Korea</td>
<td>Respiratory</td>
<td>1 ED to 1 ED</td>
<td>Physician to Physician</td>
<td>Tele-airway Management Consultation</td>
<td>Real time audio/visual</td>
<td>Randomized with no-treatment control (II)</td>
<td>E = 12 C = 13 patients</td>
</tr>
</tbody>
</table>
experience including the system, the operation procedure, the
physician/nurse satisfaction with the telemedicine experience was very high. In particular, for the GEN group, the level of clinician and patient satisfaction among nurses and patients was positive. Only two MTC studies mentioned general satisfaction among nurses and patients, and no detailed assessment was done. In the SPP studies, patients were satisfied with the consultation across diverse medical conditions (e.g., dermatology, ophthalmology, mental health), and preferred it over travelling out of town for care. In the SPP studies involving ophthalmology, specialists were consistently comfortable with tele-ophtalmology consultations and were interested in providing these services. In addition, the four studies involving trauma patients consistently reported provider satisfaction with the video and audio quality of the equipment, as well as overall ease of use of the system.

3.2.2. User perceptions

Variation was observed among the three categories of studies in relation to data transmission and networking (e.g., network coverage, memory capacity). Nevertheless, among the studies that reported patient perspectives, the level of clinician and patient satisfaction was very high. In particular, for the GEN group, the level of physician/nurse satisfaction with the telemedicine experience including the system, the operation procedure, the teleconsultation process, and the interaction with the health care professional at the other end, was high. Patients’ satisfaction was also consistently high and their overall experience with tele-emergency services was positive. Only two MTC studies mentioned general satisfaction among nurses and patients, and no detailed assessment was done. In the SPP studies, patients were satisfied with the consultation across diverse medical conditions (e.g., dermatology, ophthalmology, mental health), and preferred it over travelling out of town for care. In the SPP studies involving ophthalmology, specialists were consistently comfortable with tele-ophtalmology consultations and were interested in providing these services. In addition, the four studies involving trauma patients consistently reported provider satisfaction with the video and audio quality of the equipment, as well as overall ease of use of the system.

3.2.3. Clinical processes and outcomes

The percent of studies reporting clinical processes and outcomes associated with tele-emergency use varied across the three groups (Table 3). Of the GEN and MTC studies, 54% and 50%, respectively, presented information on clinical effects related to tele-emergency services, as compared to 89% of the SPP studies. In the GEN group of studies, physicians found the tele-emergency applications useful for remote consultation and sensitive in detecting findings (normal or abnormal). One study reported that the level of care processes and outcomes either remained constant or improved when tele-emergency services were used as reported by hospital administrators, whereas concerns were discussed in other studies about the inability to perform hands-on examination and the absence of an electronic stethoscope. In the MTC group of studies, the medical condition studied was bone fracture in most cases. Overall, the observed clinical outcomes were similar to routine practice (e.g., clinical effectiveness such as safety, patient feeling better, and returning to normal activity).

Unlike the first two groups, most of the SPP studies (89%) reported information on clinical processes and outcomes related to tele-emergency. Generally, telemedicine revealed to be clinically effective across diverse medical conditions. Examples include: limited complications and returns for re-assessment and accurate treatment among ophthalmology patients; timely administration of therapy among cardiology and pulmonary patients; timely intervention for psychiatric patients; and similarity in mortality rates compared to non-telemedicine for several conditions. Positive clinical outcomes were specifically emphasized in the five studies involving stroke patients in rural and community settings, which indicated that tele-emergency services facilitated the safe and timely administration of therapy to patients in rural areas and improved care as perceived by physicians. Good inter-rater agreement was noted in relation to diagnosis, image interpretation, and patient management between the specialist and the remote health care professionals (e.g., nurse practitioners). Superior outcomes (e.g., correct treatment decisions, functional outcomes) were also observed among patients receiving tele-emergency services compared to the telephone-based approach of communication; yet, no difference in mortality rates was indicated. In the
supported by 2/3 of the studies (or more) reporting positive outcomes.

In study designs and level of evidence (e.g., sample size, study duration, comparison group), which are not considerable; and/or (3) Consistently of tele-emergency services, when the results of the studies are: (1) In majority analyzed statistically; (2) Are minimally affected by limitations than 2/3 of the studies reporting positive outcomes.

but not for the majority of the studies; and/or (3) Not consistently supported due to less results of the studies are: (1) Not in majority analyzed statistically; (2) Are affected by some limitations in study designs and level of evidence (e.g., sample size, study duration, comparison group) but not for the majority of the studies; and/or (3) Not consistently supported due to less than 2/3 of the studies reported specific findings of outcomes in a respective category (discussion was general).

Ratings describing the extent to which evidence is conclusive in relation to each category of outcomes: Inconclusive: Used when: (1) There are reported mixed results (i.e. some studies reporting positive outcomes and other studies reporting no or negative outcomes); or (2) Less than 1/3 of the studies reported specific findings of outcomes in a respective category (discussion was general). Weak positive (+): Used when there is weak positive evidence of outcomes/impacts of tele-emergency services, when the results of the studies are: (1) Not in majority analyzed statistically; (2) Are affected by some limitations in study designs and level of evidence (e.g., sample size, study duration, comparison group); and/or (3) Not well supported due to a small number of studies (not below 1/3 of the studies in the respective group) reporting these outcomes. Modestly positive (++): Used when there is moderate positive evidence of outcomes/impacts of tele-emergency services, when the results of the studies are: (1) In majority analyzed statistically; (2) Are minimally affected by limitations in study designs and level of evidence (e.g., sample size, study duration, comparison group), which are not considerable; and/or (3) Consistently supported by 2/3 of the studies (or more) reporting positive outcomes.
case of trauma patients (four studies), physicians perceived that the tele-trauma systems improved patient care. In one study, physicians thought it saved several lives. In another study, tele-trauma consults had higher mortality than the general trauma population, which was likely explained by the higher severity level of the telemedicine group studied. Among the three studies involving patients with ophthalmology conditions, no adverse outcomes or complications were observed due to initial tele-emergency assessment, and no differences were noted compared to face-to-face examination. Last, it is worth noting that mismanagement of wounds (e.g., decision to use antibiotics), and misinterpretation of images (i.e. poor sensitivity and specificity), were reported by one study involving patients with extremity wounds.

3.2.4. Disposition and throughput
The majority of the GEN studies (82%), reported effects related to the throughput of patients, patient transfers, and ER return visits. Although a faster throughput of patients was reported and avoidable patient transfers were decreased, comparable rates of ER return visits and additional needed care were observed when tele-emergency services were used compared to regular care. Among the MTC studies, limited information was presented on disposition and throughput effects. When discussed (50% of studies), the transfer pattern of patients varied with no clear evidence of change, due to the absence of comparison groups. In the SPP studies that discussed these effects (58% of studies), the most frequently reported outcome of this type was related to the transfer of patients, which was reduced with tele-emergency services. Yet, limited evidence was available in relation to the change in length of stay and transfer time between hospitals.

3.2.5. Economic outcomes
Overall, a small number of studies in each of the three groups reported information on economic outcomes. Although cost estimates (e.g., equipment, line charges) were presented in some studies, no cost-benefit analysis was performed in any of the studies included in this review. Nevertheless, reduced hospital costs were discussed in the SPP studies (e.g., trauma and ophthalmology conditions) as a result of tele-emergency services use.

4. Discussion
Emergency care in the U.S. is plagued by multiple challenges including steadily growing demand for services, increased complexity of cases, and declining financial support [23,24]. Small and rural hospitals face particular challenges related to shortages of primary care and specialist providers [7,25]. In addition, and in light of the regionalization movement of emergency care recommended by the IOM (e.g., trauma care, heart attack, stroke), it becomes essential that hospitals have access to specialty care in order to ensure the right care at the right time for their patients [24]. Information technology is being leveraged to address these issues through telemedicine initiatives [25,26]. Yet, to date, limited evidence exists on the impact and effectiveness of these.

Our systematic search using four recommended databases identified 340 unique citations on telemedicine/telehealth in ER settings. However, three-quarters of these articles were eliminated based on multiple coders’ review as not meeting eligibility criteria, either because they were not on telemedicine applications in emergency rooms or because they did not report data. Two-thirds of the remaining articles were subsequently eliminated as not specifically evaluating tele-emergency applications in ER settings, resulting in a final set of 38 studies of telemedicine applications in ER practice that were fully coded.

An existing taxonomy [16] categorizes telemedicine applications according to discipline, purpose, technology used, and setting, and we found this a useful way to classify studies. The discipline we focused on was emergency medicine. Interestingly, within the emergency medicine discipline, all studies fell into one of three telemedicine applications—use in general ERs with diffuse patient populations, use in minor treatment clinics, or use in ER patients with specific specialized conditions.

Another component of the taxonomy [16] for categorizing telemedicine applications is purpose. We characterized the purpose of the application in terms of its scope. In tele-emergency, the most frequent scope of practice involved teleconsultation in which a hub physician provided diagnostic and treatment recommendations or second opinions. Another common activity was review of radiology images. In a few cases, the tele-emergency application provided telepresence where the hub physician took the place of an on-site remote provider. Half of the studies focused on specialty consultation, and in these applications the specialist provided in-depth expertise for patients with specific conditions, such as cardiologist review of chest pain patients or ophthalmologist examination of patients with eye injuries.

The technology used is another component of this taxonomy [16] for categorizing telemedicine applications. In hospital-based telemedicine, store and forward is a particularly common technology, especially in radiology departments where images are sent from smaller hospitals or during nights and weekends to distant locations for interpretation. However, because of the nature of emergency medicine, store and forward technology was never reported in tele-emergency studies. Instead, if images were transmitted, it was for immediate review and consultation. All studies employed simultaneous audio and video transmissions. These permitted the consulting ER physician or specialist to assist in real time. In a typical study, this technology was only employed in a fraction of cases seen in the ER, but in such situations, the cases were often patients with trauma or serious acute conditions such as stroke symptoms.

Another component of this taxonomy [16] is study setting. One popular setting dyad linked nurse-run minor treatment clinics with physicians in a host ER. These studies were all conducted in the U.K. where this model of care has been established. The second most popular setting linked one ER to another, often in a hub and spoke model where providers
in smaller ERs connected to a larger ER for live consultation, usually of particularly challenging patients such as those with complex injuries or serious acute conditions (e.g., airway blockage, acute myocardial infarction). The third popular setting dyad linked clinicians at ERs with a specialist for consultation on cases with specific conditions, such as consultation with a burn clinic for triage guidance, or consultation with a trauma surgeon for advice before transferring a seriously injured patient. Usually these specialists were not located in another ER, but instead accessed the system from their clinic office or home computer.

This taxonomy [16] does not include research methodology, but we found this also to be a useful way to classify these evaluation studies. Overwhelmingly, the studies collected data solely after tele-emergency was implemented, with only a handful incorporating a pre-post evaluation. Likewise, only a third of the studies include any type of comparison group. These limitations are somewhat understandable in that telemedicine technology makes new data sources available along with changing work processes. As pointed out previously [12], an emerging body of telemedicine research shows benefits, but the setting for studies is often restricted to a single hospital or health system, thus limiting generalizability. Our findings echo this limitation in that half of studies involved transmissions within a single hospital or pair of settings and less than a third linked more than five sites.

In terms of findings, about half of the studies reported technical quality measures, half reported process measures, and half reported patient outcomes, obviously with many studies reporting multiple findings. Consistent with the telemedicine evaluation literature, the most popular measures included technical acceptability, provider agreement on diagnosis and/or treatment recommendations, provider and/or patient satisfaction, changes in patient transfer rates, financial indicators, and case resolution [27,28]. Only a handful of studies, however, conducted statistical analyses.

Despite the potential for leveraging technology to address clinicians’ needs in emergency rooms, the limited uptake of telemedicine in hospital settings has yielded gaps in existing knowledge. In general, our search of the literature revealed only 38 published evaluation studies of telemedicine applications for emergency medicine, a discipline that could certainly benefit from immediate communication connecting distant sites. Often patient lives depend on it, particularly in trauma cases and serious acute illnesses where time to definitive treatment is paramount and where patients and clinicians at locations distant from tertiary care facilities are disadvantaged. In light of the trend towards innovation uptake by emergency care providers [24], implementing telemedicine initiatives may provide solutions to the challenge of specialist shortages in remote areas [25,29].

Despite efforts to capture all relevant empirical articles in this systematic review, limitations include the exclusion of non-English articles, unavailable articles, and citations not listed in the four searched databases. In addition, generalizability is a challenge for telehealth research due to the variability in clinical settings, scope, and technology. This review attempts to address this by grouping the results into similar settings and use (GEN, MTC, SPP). Most importantly, there were limitations in the research design and methodology of many of the studies that met the criteria for this review, which in turn limits the strength of the conclusions. This is of particular importance because conclusions relating to effectiveness of tele-emergency applications are highly dependent on the way the assessment was approached. In emerging technologies, early publications often focus on the feasibility of specific technology applications or on user satisfaction with it. A recent review [30] concluded that sufficient research has been conducted to support claims that telemedicine enhances access, is acceptable to patients and clinicians, and that technology has advanced to the point of providing high-quality information transfer. What has not yet been established is the effectiveness of most telemedicine applications [12]. This is certainly the case in the tele-emergency literature. Even though all but one of the publications claimed positive results, the study designs were weak, the measures were limited, statistical analysis was rare, and favorable conclusions were often supported by very little quantitative data. Indeed, the multitude and capabilities of the technology are expanding rapidly, constantly offering faster and more developed forms of information, often rendering current applications obsolete and outmoded [31]. To that end, reviewers are currently looking for advanced research questions that address the dynamic field of telemedicine beyond the traditional clinical and cost-effectiveness evaluations [12,27]. For tele-emergency benefits to be widely acknowledged, studies must move to multi-center investigations using an array of metrics, preferably with pre- and post-implementation designs and non-intervention comparison groups. Furthermore, there is a growing need for formative assessments that inform the future development of telemedicine with an emphasis on the understanding of telemedicine as complex development processes [12].

**Author contributions**

All authors made substantial contributions to all of the following: (1) the conception and design of the study, or acquisition of data, or analysis and interpretation of data, (2) drafting the article or revising it critically for important intellectual content, (3) final approval of the version to be submitted.

In particular:

Marcia Ward developed the concept for the systematic review, drafted the initial article, oversaw all data collection and analysis, developed the initial interpretation of the findings, and approved the final version.

Mirou Jaana revised the initial article, refined the coding scheme, analyzed the data and refined the interpretation, and approved the final version.

Nabil Natafji oversaw all coding of data, provided initial analysis of all data, assisted with the interpretation of the data, contributed to the writing of the manuscript, and approved the final version.

**Competing interests**

None.
Summary points
What was already known on the topic

- In a recent analysis of the 2011 HIMSS Analytics dataset, two of the three most frequently implemented telemedicine services were in emergency/trauma care departments and in cardiology/stroke/heart attack programs.
- Hospital-based applications of telemedicine present a potentially important solution, particularly for small and rural hospitals where access to local specialists is rarely available.
- A search for meta-analyses and systematic literature reviews on telemedicine and telehealth yielded 55 citations, of which three focused on tele-ICU and none addressed specific prevalent hospital-based applications other than tele-ICU.

What this study added to our knowledge

- Tele-emergency can be classified into three applications based on the clinical settings being connected and the target patient population served. One application focuses on telemedicine for diffuse patient populations that typically present in emergency rooms (ERs). The second application considers telemedicine in the context of minor treatment clinics for patients presenting with minor injuries or illnesses. The third application focuses on the use of telemedicine to connect providers in ERs to medical specialists for consultations on patients with specific conditions.
- Almost all tele-emergency studies reported positive findings with considerable support in terms of technical quality and user satisfaction. There were also positive findings reported for clinical processes, outcomes, throughput, and disposition, but the rigor of the studies using these measures was limited and needs additional support. Studies of economic outcomes are particularly sparse.
- Studies clearly demonstrate that tele-emergency is an application that meets the needs of small and rural hospitals to address infrequent but emergency situations requiring specialist care.
- Similarly, studies indicate that tele-emergency has considerable potential to expand use of minor treatment clinics to address access issues in remote areas and overcrowding of urban ERs.

Acknowledgments

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