Telemedicine in Acute-Phase Injury Management: A Review of Practice and Advancements

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Abstract

Objectives: *To offer a systematic review of the body of literature in the emerging field of telemedicine in the management of acute-phase injuries.* ***Materials and Methods:*** *We conducted a literature review.* ***Results:*** *Telemedicine has only recently been applied to the specialties of trauma, emergency care, and surgery. The potential benefits of telemedicine include a decrease in travel expenses, enhanced continuity of care, and increased access to specialized consultants in medically underserved and rural areas.* ***Conclusions:*** *There still exist barriers to the use of teletechnologies in medicine that limit their wider adoption. Poor infrastructure, limited equipment availability, and insufficient access to training and education for medical personnel have prevented wider use.*

Key words: *tele-health, e-health, home health monitoring intervention, trauma, extreme environments, information management*

Background

Injuries are a leading public health problem worldwide, accounting for an estimated 10% of global mortality.[1] They are also responsible for additional burdens in the form of disability and physical impairment and often result in harmful psychological sequelae.[2] However, relative to other public health problems, research on the prevention and control of injuries receives significantly less attention, especially in low- and middle-income country settings.[3]

In nearly all countries, acute injuries caused by traffic collisions, industrial incidents, or violence leads to emergency departments where substantial costs are incurred in the treatment, care, and rehabilitation of injured persons. In resource-poor and remote regions, the lack of equipment, insufficient personnel, or technical resources contributes to a less than optimal environment for acute injury management.[2]

With the adoption of population-wide measures for injury prevention,[4,5] reductions in injury morbidity and mortality have been realized during the latter half of the 20th century, particularly in high-income countries.[6] However, globally, large differences remain between and within countries regarding injury distribution, availability of treatment, and outcomes.[3]

Technological advances have also enabled advancements in the reduction of injury rates, more effective patient care, and decreases in severity.[7] Growing numbers of telemedical, telesurgical, and injury surveillance modalities have relevance for both clinical care and population-based control of acute injuries.

Our aim in this review was to examine the evidence at hand concerning worldwide trends in the development and adoption of telemedical adjuncts for injury control, focusing on acute injuries. The findings are discussed in light of various conceptual approaches relevant for the development of acute care management. Implications for preventive efforts and clinical practice are also raised.

Methods

Original research articles examining the use of telemedical applications for the treatment and management of acute traumatic injuries were obtained through a search of the literature indexed by the National Library of Medicine's PubMed/MEDLINE database. English language studies published between January 2004 and December 2010 were identified using the key words "telemedicine," "telehealth," or "mobile medicine."

This search produced 5,995 references, which was limited to 69 when we restricted the search to studies that reported the use of teletechnology only in the acute setting (i.e., articles were excluded in cases where telemedicine was used for outpatient care, office-based follow-up or consultation, rehabilitation, chronic disease management, screening programs, or interventions in non-urgent situations, such as scheduled or elective surgeries).

Studies were also excluded in cases where reports provided information concerning the development of new instrumentation that did not include data from applications in human subjects. This exclusion further restricted the search to 45 references. We read 31 of these as full articles.

Results

Table 1 presents an overview of the studies reviewed, classified according to the country or geographical region of focus, the study methodology used, indicators of interest, specific nature of the intervention or observation, and how outcome measures were analyzed.

As expected, most of the development and use of teletechnologies occurred in high-income country settings, with China,[8] Taiwan,[9,10] and Thailand being represented among middle-income countries. French researchers have developed a mobile neurosurgical unit providing support for remote military medicosurgical units that have

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Table 1. Review of Telemedical Advancements for Acute Injury Control

REFERENCE (YEAR), COUNTRY	PRIMARY OBJECTIVE	METHODS	INTERVENTION	RESULTS	AUTHORS' CONCLUSIONS
Modi et al.[12] (2010), Canada	To assess the feasibility of iPhone-based TR for the diagnosis of acute cervicodorsal spine trauma	Retrospective study of 75 cases of suspected cervicodorsal spine fracture	CT images were reviewed by two radiologists using an iPhone program.	High sensitivity and accuracy of detecting vertebral body fractures (80% and 97% by both readers [$\kappa = 1$]). Good sensitivity and accuracy of detecting posterior elements fracture (75% and 98% [$\kappa = 0.66$]).	This system is accurate in the diagnosis of acute cervicodorsal spinal trauma and allows for rapid, remote, and secure visualization of medical images without storing patient data on the iPhone.
Dulou et al.[11] (2010), France	Presentation of the French concept of a mobile MNSU to provide specific support to remote military medicosurgical units deployed in Africa, South America, Central Europe, and Afghanistan	Descriptive program evaluation	From 2001 to 2009, 15 missions were performed, for 16 patients. All but 3 of these missions (those in Kosovo, French Guyana, and Afghanistan) concerned Africa.	11 patients were French soldiers, 3 were civilians, and 2 were Djiboutian soldiers. The conditions for which MNSUs were requested included craniocerebral wounds (2 cases), closed head trauma (7 cases), spinal trauma (5 cases), and spontaneous intracranial hemorrhage (2 cases). In 5 of the 16 cases, neurosurgical treatment was provided on site.	The MNSU can be deployed for timely treatment when some delay in neurosurgical management is acceptable.
Sposaro and Tyson[13] (2009), United States	Presentation of an Android-based smartphone alert system for fall detection and activation of emergency response	Descriptive program evaluation	Using an integrated triaxial accelerometer and algorithm that adapts to unique movements that a phone experiences without the need for the use of sensors on the body	If a fall is suspected a notification is raised requiring the user's response. If the user does not respond, the system alerts prespecified social contacts with an informational message via SMS. If a fall is confirmed, an appropriate emergency service is alerted.	The system provides a realizable, cost-effective solution to fall detection using a simple graphical interface.
Saffle et al.[21] (2009), United States	Evaluation of a TM program for acute burns	Descriptive program evaluation	Created a TM network linking a burn center to three hospitals located 298–350 air miles away. The study compared consults and referrals from these facilities from July 2005 to August 2007.	During the study period, 80 patients were referred, 70 of whom were seen acutely by TM, compared with 28 pre-study referrals. Only 31 patients seen by TM received emergency air transport (44.3%), compared with 100% of pre-study patients ($p < 0.05$). Study patients transported by air had larger burn sizes (9.0% versus 6.5% total body surface area; $p =$ NS) and longer lengths of stay (13.0 days versus 8.0 days; $p =$ NS) than pre-study patients.	Acute evaluation of burn patients can be performed accurately by TM, reducing undertriage or overtriage for air transport, improving resource utilization, and enhancing and extending burn center expertise to many rural communities at low cost.

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Table 1. Review of Telemedical Advancements for Acute Injury Control *continued*

REFERENCE (YEAR), COUNTRY	PRIMARY OBJECTIVE	METHODS	INTERVENTION	RESULTS	AUTHORS' CONCLUSIONS
Latifi et al.[24] (2009), United States	Report of the initial experience of a TM program connecting five rural hospitals with a Level I trauma center	Retrospective analysis of 59 teleconsults	Implementation of a teletrauma program	59 trauma (35 [59%]) and general surgery (24 [41%]) patients were evaluated. For 6 patients, the teletrauma consults were considered potentially lifesaving; 17 patients (29%) were kept in the rural hospitals. Treating patients in the rural hospitals avoided transfers, saving an average of USD 19,698 per air transport or USD 2,055 per ground transport.	The telepresence of a trauma surgeon aids in the initial evaluation, treatment, and care of patients, improving outcomes and reducing the costs of trauma care.
Knobloch et al.[19] (2009), Germany	Evaluation of the use of teletechnology to transfer images of burn injuries to the responsible burn consultant at any point of time in the most convenient manner	Case report/letter to the editor	Used a Nokia N95 cell phone to obtain digital images of a patient suffering a high-voltage burn injury to the lateral foot and another patient who underwent free microsurgical groin flap due to submental burn contracture	A cell phone-based multimedia messaging service is feasible and accurate in transferring a more comprehensive impression of postoperative flap assessment to the microsurgical consultant after office hours.	Irrespective of the geographic location of the consultant, the use of the cell phone-based MMS photo and videotransmission facilitates immediate decision-making.
Keane[18] (2009), United Kindgom	Literature review for articles on the role of TM in accident and emergency work	Literature review	Review of the findings of 39 articles from 21 independent groups using TM in an emergency medicine setting	TM has been applied in a variety of settings—from medical advice for paramedics in the disaster setting to patient follow-up in the fracture clinic. Various communications equipment was used, including radio links, telephone, e-mail, and mobile wireless videoconferencing devices. All such links have been found to transfer information effectively, but success has sometimes been limited by technical failure and by staff lacking confidence in using the systems.	Although the accident and emergency setting is well suited to the application of TM, larger trials and cost-effectiveness studies are required in this area.
Juhra et al.[25] (2009), Germany	Description of a pilot project integrating TM into the TraumaNetwork NorthWest	Program description	Description of program framework	No results	If this pilot project is successful, this framework will be adapted across Germany.
Di Paolo et al.[26] (2009), Italy	Details from two cases from the authors' forensic archive database in which failure to activate the TR system was related to unfavorable outcomes	Case review	Review of case autopsy reports of two patients after unexpected death following road accidents	In both cases, the lethal outcome was due to the failure to obtain accurate radiological diagnoses that could have been established by activating the TR service.	There is a risk for adverse outcomes when teleradiologists are excluded from the management of patients in the emergency setting.

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Table 1. Review of Telemedical Advancements for Acute Injury Control *continued*

REFERENCE (YEAR), COUNTRY	PRIMARY OBJECTIVE	METHODS	INTERVENTION	RESULTS	AUTHORS' CONCLUSIONS
Waran et al.[15] (2008), United States	Description of the use of an existing mobile phone network and conventional hand phones with built-in cameras to capture images from hard copies of scan images and transferring these images from a hospital without neurosurgical services to a university hospital with tertiary neurosurgical service for consultation and management plan	Case series	14 patients with acute neurosurgical problems admitted to a general hospital in a 6-month period had their images photographed and transferred in JPEG format to a university neurosurgical unit.	In all of the 9 patients with acute head injury and 5 patients with acute nontraumatic neurosurgical problems, both neurosurgeons agreed that a diagnosis could be made on the basis of the images that were transferred.	Accurate diagnosis and meaningful decisions can be based on images of acute neurosurgical problems transferred using a conventional camera phone. This method of consultation proved highly convenient and cost-effective.
Kreutzer et al.[27] (2008), Germany	Evaluation of an analog image transfer system for the presentation of CT and magnetic resonance imaging scans from seven referring hospitals in southern Germany.	Retrospective case series	1,024 neurosurgical cases (945 patients) seen between June 1995 and June 2000 for which TR was performed	Analysis showed that in 67% of cases admission to the neurosurgical center was not necessary. The potential savings for ground transportation were € 339.93 per case (€ 1 = US$ 1.40). The total cost of the image transfer system for all eight hospitals was € 96,000; this was amortized after 282 TCs, which occurred after 15 months of usage.	A simple TR system in neurosurgery enables rapid and reliable TCs, mainly on patients with trauma, stroke, and intracerebral hematoma at low cost.
Dyer et al.[28] (2008), Canada	Evaluation of the use of TS protocols during acute trauma resuscitations	Case series	Used an existing Internet link (allowing bidirectional videoconferencing and unidirectional US) to direct or observe an EFAST adapted from NASA algorithms	Three normal volunteers and 20 acute clinical examinations were completed. Technical challenges included initiating US audio and video communications, image freezing, and US transmission delays. Enhancement of clinical care included confirmation of five cases of hemoperitoneum and two pneumothoraces, as well as educational benefits.	Remote real-time guidance or observation of an EFAST using TS appears feasible. Most technical problems were quickly overcome. Further evaluation of this approach and technology is warranted in more remote settings with less experienced personnel.

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Table 1. Review of Telemedical Advancements for Acute Injury Control *continued*

REFERENCE (YEAR), COUNTRY	PRIMARY OBJECTIVE	METHODS	INTERVENTION	RESULTS	AUTHORS' CONCLUSIONS
Duchesne et al.[29] (2008), United States	Analysis of outcomes before and after implementation of TM in the management of rural trauma patients initially treated at local community hospitals before transfer to trauma centers	Case series	All trauma patients treated at seven rural emergency departments in Mississippi equipped with dual video cameras with remote control capability were reviewed.	During 5 years, 814 traumatically injured patients presented to the local community hospital. Before TM, 351 patients were transferred directly for definitive management. In the post-TM period, 463 virtual consults were received, of which 51 patients were triaged to the trauma center. There was a significant decrease in hospital cost when comparing post-TM and pre-TM eras (USD 1,126,683 versus 7,632,624, $p < 0.001$).	TM significantly improved rural evaluation and management of trauma patients. More severely injured trauma patients were more rapidly identified and transferred. Total trauma center costs were significantly decreased without significant changes in mortality. Introduction of TM consultation to rural emergency departments expanded local trauma capabilities and conserved trauma center resources.
Tsai et al.[10] (2007), Taiwan	Evaluation of the effectiveness of video-TM for the preflight screening of patients for air medical transports	Cross-sectional study	Stage 1, retrospective review of medical records of patients transported from the Penghu Islands to Taiwan from November 1999 to October 2002. Stage 2, collection of medical records of patients who were preflight-screened by physicians using video Web cameras from November 1, 2002 through August 30, 2003	In total, 822 transfers were included. In a comparison of flight frequencies between the two stages, the results revealed a 36.2% reduction of emergency air medical transport applications in Stage 2. The flight approval rate was 91.2%. The intervention in Stage 2 also presented a significant reduction in cross-zone transport (from 16.1% to 0.1% to the northern Taiwan region). Within-zone transfers increased from 74.9% to 88.3%. Cost analysis showed that physician triage in Stage 2 resulted in a total annual savings on EAMTs of USD 448,986.	Physician-assisted preflight screening using video-TM significantly reduced the frequency of unnecessary air medical transports and consequently led to reduced costs. Video-TM can be an essential tool to support physicians in decision-making for patient screening.
Todder et al.[14] (2007), Israel	Evaluation of the feasibility of videoconference TM for acute trauma care in areas where armed conflict compromises accessibility and prevents direct physical access	Case series	Two cases where videoconferencing was successfully used to provide specialist care for acute trauma rapidly and in a safe and accessible environment	Case 1: Gradual yet significant improvement was observed, and he asked to cease treatment. Case 2: The patient remained in follow-up for moderate PTSD for 6 months through the videoconference link. She improved in terms of the frequency and intensity of the dissociative episodes as well as general daily functioning.	Our experience suggests that this means of acute trauma intervention could represent an effective solution for healthcare providers.

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Table 1. Review of Telemedical Advancements for Acute Injury Control *continued*

REFERENCE (YEAR), COUNTRY	PRIMARY OBJECTIVE	METHODS	INTERVENTION	RESULTS	AUTHORS' CONCLUSIONS
Ma et al.[30] (2007), United States	Review of reports detailing the use of US in TM	Literature review	Review of the findings of 10 independent groups using US in the urgent and emergency setting	From earthquakes in Armenia and Turkey, to space travel, US has proven invaluable when combined with satellite transmission and real-time interpretation to support medical activities.	Because of its portability, reproducibility, accuracy, and ease of use, US will continue to play an important role in medicine.
Latifi et al.[31] (2007), United States	Review of the development of a TM program	Case report and program review	Use of telepresence at the university medical center in Tucson, AZ for an integrated and collaborative community approach to solve the lack of trauma and emergency care issue in the region	A successful teletrauma program requires careful planning, a sophisticated TM network, technical support on a 24-h basis, and a well-developed business plan, with a detailed operational procedure manual. Most importantly, it requires buy-in by physicians, nurses, administrators, and the public.	TM will become a major tool in trauma care and education, allowing direct help to small hospitals without trauma specialists, potentially reducing costs, and preventing unnecessary transfers.
Kwon et al.[32] (2007), United States	Evaluation of the use of non-physician operators to obtain diagnostic US images for remote medical diagnosis	Case series	Remote guidance musculoskeletal examinations were conducted by athletic trainers. Images were transmitted to remote experts for interpretation.	Real-time US videostream and still capture images from 32 athletes were considered adequate for diagnostic interpretation.	US can be used in locations without a high level of on-site expertise. A non-physician with minimal training can perform complex, diagnostic-quality examinations when directed by a remote-based expert.
Chandhanayingyong et al.[33] (2007), Thailand	Investigation of the accuracy and usefulness of TC using the mobile phone MMS in emergency orthopedic patients	Cross-sectional study	Pictures of radiographs were taken using a built-in 1.3 megapixel mobile phone camera from a digital display screen in the emergency room and then transmitted to the camera phones of four assessors.	The overall misdiagnosis rate was 40%, with overdiagnosis of 12% and underdiagnosis of 27%. The consequence of misdiagnosis would have resulted in mismanagement in up to 48% of the cases.	TC via MMS demonstrated good reliability, but poor diagnostic accuracy, which could have major consequences in emergency orthopedic patients.
Boissy et al.[34] (2007), United States	Evaluation of a user-based motion sensing and fuzzy logic for automated fall detection in older adults	Clinical trial	10 healthy participants were instrumented on the front and side 3D accelerometers. Participants simulated 9 fall conditions and 6 common activities of daily living.	There were 750 events (45 fall events and 30 non-fall events per participant). The proposed algorithm detected fall events during simulated fall conditions with a success rate of 93% and a false-positive rate of 29% during non-fall conditions.	Automated detection of fall events shows promising results, but additional optimization of the algorithm will be needed to decrease the false-positive rate.

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Table 1. Review of Telemedical Advancements for Acute Injury Control *continued*

REFERENCE (YEAR), COUNTRY	PRIMARY OBJECTIVE	METHODS	INTERVENTION	RESULTS	AUTHORS' CONCLUSIONS
Ashkenazi et al.[35] (2007), Israel	To assess the effect of TR on the need for transfer of head-injured victims	Prospective cohort study	Digital copies of CT scans of head-injured patients admitted to a rural Level 2 trauma center were transferred to a neurosurgical referral center via TR.	Of 209 trauma victims with neurosurgical pathology in need of hospitalization, 126 (60.2%) were immediately transferred, whereas 83 (39.7%) were hospitalized in the rural Level 2 trauma center for observation.	With the availability of a TR system and neurosurgical consultation, selective head-injured patients with pathological CT scan may be safely managed in Level 2 trauma centers.
Wong et al.[8] (2006), China	Comparison of process-of-care indicators, clinical outcomes, and cost-effectiveness among TC, TR, and VC	Randomized clinical trial	Patients with emergency neurosurgical conditions (head injury, stroke, etc.) from a district general hospital were randomized to three different modes of consultation. Process-of-care indicators (post-resuscitation Glasgow Coma Scale score, consultation time required, diagnostic accuracy, and transfer decision and safety), 6-month clinical outcome, and cost-effectiveness of the three consultation modes were correlated.	In a 3-year period, 710 patients were recruited and randomized to the three consultation modes ($n=235$, 239, and 236, respectively). TR and VC showed a definite advantage in diagnostic accuracy over TC (89.1 and 87.7% versus 63.8%; $p<0.001$). However, duration of the corresponding consultation process was longer for TR and VC than TC (1.01 and 1.3 h versus 0.70 h). A high failure rate (30%) was noted in VC. Thirty-three percent of patients were transferred to the neurosurgical center after consultation. The difference in consultation modes did not have an impact on transfer rate and safety. There was a trend toward more favorable outcome (61%; $p=0.12$) and a reduced mortality (25%; $p=0.025$) in TR compared with TC (54 and 34%, respectively) and VC (54 and 33%, respectively). The mean cost per patient in the VC group was slightly higher than the other two groups (TC versus TR versus VC= 14,000 USD versus 14,400 USD versus 16,300 USD, respectively), but the differences were not statistically significant.	Emergency neurosurgical consultation assisted by TR and VC achieved a higher diagnostic accuracy in comparison with conventional TC. Although VC did not show an advantage over TR in process-of-care indicators, clinical outcome, and cost, it has been demonstrated to be a safe mode of consultation in emergency neurosurgery.

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Table 1. Review of Telemedical Advancements for Acute Injury Control *continued*

REFERENCE (YEAR), COUNTRY	PRIMARY OBJECTIVE	METHODS	INTERVENTION	RESULTS	AUTHORS' CONCLUSIONS
Saffle[20] (2006), United States	Commentary on the status and need for TM, highlighted by several cases that could have benefited from the technology	Case report and commentary	None	In one case, a patient who was transported unnecessarily, leading to air transport costs that were almost USD 14,000. In the other case, the emergency room physician forwarded images via cell phone to the specialist, and it was determined that transport was not required, sparing significant time and expense. Similar evidence of the benefits of TM was offered from other studies.	While these cases illustrate the potential for TM to facilitate burn treatment and bring increasingly centralized, state-of-the-art burn care expertise within reach of every patient in the United States, more studies will be needed to prove the safety and efficacy of TM in acute care.
Kumar et al.[36] (2006), Australia	Demonstration—from a health provider perspective—of an Internet-based service's impact on emergency eye care in rural Australia	Case series	The teleophthalmology service was initiated in the Carnarvon Regional Hospital of the Gascoyne region in Western Australia. A digital, slit lamp, and fundus camera were used for the service.	118 persons took part in teleophthalmology consultations. Emergency cases constituted 3% of these consultations. In the previous year, there were 7 eye-related emergency evacuations (inter-hospital air transfers).	Implementation of Internet-based health services has a marked impact on rural emergency eye care delivery. The Internet is well suited to ophthalmology for the diagnosis and management of acute conditions in remote areas. Integration of such services to mainstream health care is recommended.
Noble et al.[16] (2005), United Kingdom	A cost-consequences analysis of minor injury treatment using TM was performed alongside a randomized controlled trial in a United Kingdom peripheral emergency department.	Nested cross-sectional	For 253 patients, the main outcome measures were safety and clinical effectiveness and cost to the patient and NHS 7 days after presentation.	The mean cost to the NHS for the TM patients was 78.61 GBP and for those assessed routinely was 39.15 GBP. For costs incurred by patients and their families the respective figures were 58.24 GBP and 43.95 GBP.	TM was a more expensive option for providing minor injury care in a general practitioner-supported peripheral emergency department, while consequences did not vary greatly between the different options.
Smith et al.[22] (2004), Australia	Qualitative analysis of a virtual outpatient service established in Queensland for the delivery of post-acute burn care to children living in rural and remote areas of the state	Retrospective cohort	293 patient consultations over a period of 3 years	A retrospective review of the authors' experience has shown that post-acute burns care can be delivered using videoconferencing, e-mail, and the telephone. The families of patients have expressed a high degree of satisfaction with the service.	Telepediatric services have helped improve access to specialist services for people living in rural and remote communities throughout Queensland.

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Table 1. Review of Telemedical Advancements for Acute Injury Control *continued*

REFERENCE (YEAR), COUNTRY	PRIMARY OBJECTIVE	METHODS	INTERVENTION	RESULTS	AUTHORS' CONCLUSIONS
Smith et al.[37] (2004), Australia	An analysis of diagnostic accuracy of and patient satisfaction with TM for the follow-up of pediatric burns patients	Cohort study	35 children with a previous burn injury were studied. 25 children received three consecutive assessments: first FTF by a consultant in the outpatient department, then by a second consultant who reviewed the patient via videoconference, and then by the second consultant in person. The following variables were measured: scar color and thickening, contractures, range of motion, patient's level of general activity, any breakdown of the graft site, and adequacy of the consultation.	Agreement between the two consultants when seeing patients FTF was moderately high, with an overall concordance of 85%. When videoconferencing was used, the level of agreement was almost the same, at 84%. If one consultant reviewed patients FTF first and then via videoconference, the overall concordance was 98%; if the process was reversed, the overall concordance was 97%.	This study confirms that the quality of information collected during a videoconference appointment is comparable to that collected during a traditional, FTF appointment for a follow-up burns consultation.
Nguyen et al.[17] (2004), United States	Assessment of the efficacy and efficiency of burn visits via TM and identification of barriers and benefits specific to burn care	Retrospective cohort	Data were evaluated from 1,000 burn follow-up visits with 294 patients via TM during a 5-year interval.	The benefits of TM include a decrease in travel expenses, improved continuity of care, and increased access to specialized consultants.	TM burn visits are a cost-effective clinical alternative for the patient. However, TM can be a financial burden to healthcare systems and inefficient for healthcare providers.
Marcin et al.[38] (2004), United States	Description of a pilot TM project that allows a remote trauma center's adult intensive care unit to obtain non-trauma, nonsurgical-related pediatric critical care consultations for acutely injured children	Prospective cohort	TM consultations were obtained at the discretion of the remote intensive care unit provider for non-trauma, nonsurgical medical issues.	39 consultations were conducted on 17 patients from the 97 pediatric patients admitted during the 2-year study. Patients who received consultations were younger (5.5 years versus 13.3 years, $p < 0.01$) and were more severely injured (mean ISS = 18.3 versus 14.7, $p = 0.07$). Severity-adjusted mortality rates were consistent with trauma and ISS expectations. Satisfaction surveys suggested a high level of provider and parental satisfaction.	This report of a trauma intensive care unit-based pediatric critical care TM program demonstrates that TM consultations to a remote intensive care unit are feasible and suggests a high level of satisfaction among providers and parents.

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Table 1. Review of Telemedical Advancements for Acute Injury Control *continued*

REFERENCE (YEAR), COUNTRY	PRIMARY OBJECTIVE	METHODS	INTERVENTION	RESULTS	AUTHORS' CONCLUSIONS
Hsieh et al.[9] (2004), Taiwan	A feasibility study of TC with the mobile camera phone in digital soft tissue injury	Case series	Pictures of the injured digit(s) or radiographs were taken by surgical residents in the emergency room and transmitted to another camera phone to be viewed by the remote consultant.	45 patients with injuries of 81 digits were analyzed. In 12 cases (15%) there was disagreement between the TC and the actual treatment. In image reviewing, there was 79% sensitivity and 71% specificity in remote diagnosis of the skin defect and 76% sensitivity and 75% specificity in remote identification of the bone exposure regarding the concordance of opinions of all three surgeons. There was significant discordance in triaging in 20 cases (25%), and the difference was partly attributed to the inability of the camera to show fine details or, in some cases, low-resolution digital images resulting from a bloody oozing wound.	TM using a mobile camera phone is feasible and valuable for early diagnosis and triaging of digital soft tissue injury in emergency cases, with online verbal communication and review of the transmitted captured images. This system has the advantages of ease of use, low cost, high portability, and mobility. With advances in hardware for digital imaging and transmission technology, this system has potential for future applications in TM and telecare.
Benger et al.[39] (2004), United Kingdom	To determine the safety of minor injuries using TM compared with on-site specialist care, current practice, and a robust gold standard, and to assess the clinical effectiveness of this new technique	Prospective cohort study	Patients presenting to a peripheral hospital within 10 days of injury were separately assessed by an emergency medicine specialist using TM, a second on-site emergency medicine specialist, and an on-site general practitioner. The primary outcome measures were discrepancies among these three medical assessments and a gold standard. All patients were subsequently randomized to follow one of the independent treatment plans generated by the above assessments. Secondary outcomes were recovery and further use of healthcare services, measured 7 days after recruitment, and duration of consultation.	600 patients were recruited over a 12-month period. Overall, 73 discrepancies were identified, with 12 important overtreatments and 11 important undertreatments. No consultation modality was clearly superior to any other, and there were no statistically significant differences in the secondary outcomes of clinical effectiveness measured at 7 days. The mean duration of a TM consultation (6.0 min) was almost twice as long as an on-site specialist (3.1 min) or on-site general practitioner consultation (3.4 min) ($p < 0.0001$ in both cases).	TM for minor injuries is safe and clinically effective, provided that care is equivalent to specialist on-site assessment and the current practice of treatment by a general practitioner. There is no evidence that TM provides superior care, and there are several process issues that may impede successful implementation of this new technique.

3D, three-dimensional; CT, competed tomography; EAMT, emergency air medical transport; EFAST, extended focused assessment with sonography for trauma; FTF, face-to-face; GBP, Great Britain pounds; ISS, Injury Severity Score; MMS, multimedia messaging service; MNSU, mobile neurosurgical unit; NASA, National Aeronautics and Space Administration; NHS, National Health Service; NS, not significant; PTSD, posttraumatic stress disorder; SMS, short message service; TC, telephone consultation; TM, telemedicine; TR, teleradiology; TS, telesonography; US, ultrasonography; USD, U.S. dollars; VC, video consultation.

been deployed in international settings, including low- and middle-income countries.[11]

The range of modalities either available or under development include the use of m-health (mobile and smart phone systems) for diagnosis[12] and preventive detection and emergency response[13] to screening[10] and teleconsultations[14] where armed conflict would otherwise compromise access to patients.

The results of these integrative modalities demonstrated high sensitivity and specificity,[12] high reliability, simplicity, and cost-effectiveness.[13,15] Wider recommendations for further integration in trauma care have also been advanced.[14]

Although these studies present several key implications for reach and cost-effectiveness, there still exist barriers to wider adoption. In one study, for example, the benefits of telemedical interventions for minor injuries were negligible.[16] Other studies raised concerns over the cost-effectiveness of telemedical interventions as well as highlighting possible gaps in efficiency brought on by the implementation of such systems.[17,18]

Modalities ranging from transmitting patient information via e-mail, video, and mobile camera phone to using wireless cellular data service and multimedia messaging services analysis demonstrated that teletechnologies provide important adjuncts to clinical decision-making and support reductions in the mortality and morbidity associated with acute trauma. The integration of these services into mainstream healthcare has been recommended by several independent lines of investigation.[11,19–21]

Discussion

Our review documents that teletechnology allows specialty care to be offered in resource-poor settings,[11] although evaluations of interventions appear to occur mainly outside of low- and middle-income country settings,[19–22] where they appear to be particularly beneficial.[11]

Several advances have been made in communications technologies adopted for use in clinical settings. Using remote and Internet-based systems as tools in acute care settings, telemedical applications have emerged as useful bridges between pre-hospital, community-based interventions and care delivered in conventional hospital settings. In the care of acutely injured trauma patients, teletechnologies have been shown to be particularly useful.

By permitting specialty trauma care to be offered in rural and resource-poor settings, teletechnologies expand the reach and scope of care previously limited to specialized trauma centers. Such developments support improved health outcomes and a higher quality of care. The limitations of teletechnology adoption include poor infrastructure, limited equipment availability, and insufficient access to training and education for medical personnel, especially in resource-poor settings.

Conclusions

Although teletechnologies in medicine have been demonstrated to be useful in the care of acutely injured patients, there still exist barriers to their use that limit their wider adoption. As long as factors persist that limit the adoption of teletechnologies in resource-poor settings, there may be a limit to the health benefits that would otherwise be realized.[23]

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No competing financial interests exist. E.R.L. conducted the review and drafted the manuscript in consultation with all co-authors. M.L.W. coordinated the study. C.A.T. collaborated in the organization of the review and participated in the analysis of the manuscripts. V.W.A.M. participated in the interpretation of the results and revision of the manuscript.

REFERENCES

1. Bhalla K, et al. Availability and quality of cause-of-death data for estimating the global burden of injuries. *Bull World Health Organ* **2010;**88:831–838C.
2. Peden M, et al. World report on child injury prevention. **2008**. Available at http://whqlibdoc.who.int/publications/2008/9789241563574_eng.pdf (last accessed November 17, 2011).
3. Hofman K, et al. Addressing the growing burden of trauma and injury in low- and middle-income countries. *Am J Public Health* **2005;**95:13–17.
4. Haddon W Jr. Options for the prevention of motor vehicle crash injury. *Isr J Med Sci* **1980;**16:45–65.
5. O'Neill B, et al. Automobile head restraints—Frequency of neck injury claims in relation to the presence of head restraints. *Am J Public Health* **1972;**62: 399–406.
6. Centers for Disease Control and Prevention. Ten great public health achievements—Worldwide, 2001–2010. *MMWR Morb Mortal Wkly Rep* **2011;**60:814–818.
7. Ricci MA, et al. Telemedicine reduces discrepancies in rural trauma care. *Telemed J E Health* **2003;**9:3–11.
8. Wong HT, et al. The comparative impact of video consultation on emergency neurosurgical referrals. *Neurosurgery* **2006;**59:607–613; discussion 607–613.
9. Hsieh CH, et al. Teleconsultation with the mobile camera-phone in digital soft-tissue injury: A feasibility study. *Plast Reconstr Surg* **2004;**114:1776–1782.
10. Tsai SH, et al. The effectiveness of video-telemedicine for screening of patients requesting emergency air medical transport (EAMT). *J Trauma* **2007;**62:504–511.
11. Dulou R, et al. The French mobile neurosurgical unit. *Neurosurg Focus* **2010;**28:E13.
12. Modi J, et al. iPhone-based teleradiology for the diagnosis of acute cervico-dorsal spine trauma. *Can J Neurol Sci* **2010;**37:849–854.
13. Sposaro F, Tyson G. iFall: An Android application for fall monitoring and response. *Conf Proc IEEE Eng Med Biol Soc* **2009;**2009:6119–6122.
14. Todder D, Matar M, Kaplan Z. Acute-phase trauma intervention using a videoconference link circumvents compromised access to expert trauma care. *Telemed J E Health* **2007;**13:65–67.
15. Waran V, et al. Teleconferencing using multimedia messaging service (MMS) for long-range consultation of patients with neurosurgical problems in an acute situation. *J Trauma* **2008;**64:362–365; discussion 365.
16. Noble SM, Coast J, Benger JR. A cost-consequences analysis of minor injuries telemedicine. *J Telemed Telecare* **2005;**11:15–19.

17. Nguyen LT, et al. Telemedicine follow-up of burns: Lessons learned from the first thousand visits. *J Burn Care Rehabil* **2004;**25:485–490.

18. Keane MG. A review of the role of telemedicine in the accident and emergency department. *J Telemed Telecare* **2009;**15:132–134.

19. Knobloch K, Rennekampff HO, Vogt PM. Cell-phone based multimedia messaging service (MMS) and burn injuries. *Burns* **2009;**35:1191–1193.

20. Saffle JR. Telemedicine for acute burn treatment: The time has come. *J Telemed Telecare* **2006;**12:1–3.

21. Saffle JR, et al. Telemedicine evaluation of acute burns is accurate and cost-effective. *J Trauma* **2009;**67:358–365.

22. Smith AC, et al. Diagnostic accuracy of and patient satisfaction with telemedicine for the follow-up of paediatric burns patients. *J Telemed Telecare* **2004;**10:193–198.

23. Blignault I, Kennedy C. Training for telemedicine. *J Telemed Telecare* **1999;**5(Suppl 1):S112–S114.

24. Latifi R, Hadeed GJ, Rhee P, O'Keeffe T, Friese RS, Wynne JL, et al. Initial experiences and outcomes of telepresence in the management of trauma and emergency surgical patients. *Am J Surg* **2009;**198:905–910.

25. Juhra C, Vordemvenne T, Hartensuer R, Uckert F, Raschke MJ. Telematics in acute trauma care. *Stud Health Technol Inform* **2009;**143:467–471.

26. Di Paolo M, Guidi B, Picano E, Caramella D. Emergency radiology without the radiologist: The forensic perspective. *Radiol Med* **2009;**114:475–483.

27. Kreutzer J, Akutsu H, Fahlbusch R, Buchfelder M, Nimsky C. Teleradiology in neurosurgery: Experience in 1024 cases. *J Telemed Telecare* **2008;** 14:67–70.

28. Dyer D, Cusden J, Turner C, Boyd J, Hall R, Lautner D, et al. The clinical and technical evaluation of a remote telementored telesonography system during the acute resuscitation and transfer of the injured patient. *J Trauma* **2008;**65:1209–1216.

29. Duchesne JC, Kyle A, Simmons J, Islam S, Schmieg RE Jr, Olivier J, et al. Impact of telemedicine upon rural trauma care. *J Trauma* **2008;**64:92–97; discussion 97–98.

30. Ma OJ, Norvell JG, Subramanian S. Ultrasound applications in mass casualties and extreme environments. *Crit Care Med* **2007;**35(5 Suppl):S275–S279.

31. Latifi R, Weinstein RS, Porter JM, Ziemba M, Judkins D, Ridings D, et al. Telemedicine and telepresence for trauma and emergency care management. *Scand J Surg* **2007;**96:281–289.

32. Kwon D, Bouffard JA, van Holsbeeck M, Sargsyan AE, Hamilton DR, Melton SL, et al. Battling fire and ice: Remote guidance ultrasound to diagnose injury on the International Space Station and the ice rink. *Am J Surg* **2007;**193:417–420.

33. Chandhanayingyong C, Tangtrakulwanich B, Kiriratnikom T. Teleconsultation for emergency orthopaedic patients using the multimedia messaging service via mobile phones. *J Telemed Telecare* **2007;**13:193–196.

34. Boissy P, Choquette S, Hamel M, Noury N. User-based motion sensing and fuzzy logic for automated fall detection in older adults. *Telemed J E Health* **2007;**13:683–693.

35. Ashkenazi I, Haspel J, Alfici R, Kessel B, Khashan T, Oren M. Effect of teleradiology upon pattern of transfer of head injured patients from a rural general hospital to a neurosurgical referral centre. *Emerg Med J* **2007;**24: 550–552.

36. Kumar S, Yogesan K, Hudson B, Tay-Kearney ML, Constable IJ. Emergency eye care in rural Australia: Role of Internet. *Eye (Lond)* **2006;**20: 1342–1344.

37. Smith AC, Kimble R, Mill J, Bailey D, O'Rourke P, Wootton R. Diagnostic accuracy of and patient satisfaction with telemedicine for the follow-up of paediatric burns patients. *J Telemed Telecare* **2004;**10:193–198.

38. Marcin JP, Schepps DE, Page KA, Struve SN, Nagrampa E, Dimand RJ. The use of telemedicine to provide pediatric critical care consultations to pediatric trauma patients admitted to a remote trauma intensive care unit: A preliminary report. *Pediatr Crit Care Med* **2004;**5:251–256.

39. Benger JR, Noble SM, Coast J, Kendall JM. The safety and effectiveness of minor injuries telemedicine. *Emerg Med J* **2004;**21:438–445.

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