Prehospital Telemedical Emergency Management of Severely Injured Trauma Patients*
A Systematic Review

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Methods Inf Med

Summary

Background Trauma is a global burden. Emergency medical services (EMS) provide care for individuals who have serious injuries or suffered a major trauma.

Objective This paper provides a comprehensive overview of telemedicine applications in prehospital trauma care.

Methods We conducted a systematic review according to PRISMA guidelines. We identified articles by electronic database search (PubMed, EMBASE, the Cochrane Library, CINAHL, SpringerLink, LIVIVO, DARE, IEEE Xplore, Google Scholar and ScienceDirect) using keywords related to prehospital settings, ambulance, telemedicine and trauma. Search terms and inclusion criteria were specified a priori by the PICOS template and revised throughout a configurative approach iteratively, to outline the complexity and variety of different telemedical concepts.

Results A final sample of 15 records was systematically selected. Most interventions were piloted and/or evaluated in Germany for trauma victims in prehospital settings. Six studies were simulated scenarios. Telemedical assistance (TMA) via real-time telemetry systems (RTS), enabling video and audio conferencing between EMS by tele-emergency physicians (TEP) were associated with a higher treatment quality and a shorter time-to-treatment in invasive procedures. By initiating in-hospital preparations based on telemedical prehospital notification (TPN), loss of information during the clinical handover was reduced and in-hospital protocols were activated with high accuracy. Remotely guided ultrasound (TeleUltrasound) by TEP showed an overall high diagnostic accuracy in simulations. Technical solutions were reliable, seemed practical and auspicious.

Conclusion The review indicates that TMA and TPN are accompanying telemedical concepts in out-of-hospital trauma care. Well-designed populated studies are needed to fully assess the effect of telemedicine in acute trauma care. Therefore, evidence regarding the effectiveness of telemedicine in prehospital setting for trauma patients is still limited.

Keywords ► telemedicine ► EMS ► ambulance ► acute trauma care ► systematic review

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Background

Trauma or injuries are the leading cause of death\(^1\) and most common reason for emergency department (ED) visits for adolescents and young adults.\(^2\) Trauma includes suicidal behaviour, falls of older adults, burns, violence or road traffic injuries.\(^6,7\) Each year, about 1.34 million people die as a result of road traffic crashes, whereas 10 million are severely injured annually.\(^2\) In comparison, diabetes mellitus causes about 1.5 million deaths every year. Severe trauma is responsible for the world's highest loss of potential life.\(^2\) For one-fifth of illness-related loss of employment years,\(^8\) for poor long-term health-related quality of life (HRQOL)\(^11\) and a major factor in permanent disability. Injuries are also a leading cause of disabilities, measured in disability-adjusted life-years (DALYs)\(^12,13\) and accounted for about 11% of the total disease burden globally.\(^7,14\) Impairments in physical and psychosocial functioning are prevalent and can have severe lifelong consequences for the injured person (e.g. symptoms of posttraumatic stress disorder after mild traumatic brain injury).\(^15\)

Between 5 and 25% of treated major traumata result in preventable deaths, and errors in treatment are most frequently encountered in the prehospital stage.\(^16–20\) Nearly 40% of the patients with a major trauma die before they reach the hospital.\(^21\) The prehospital care phase of the acute trauma continuum is a critical component of a complex care delivery system. Acute trauma care requires rapid assessment of severity, on-scene stabilization of vital signs and prompt in-hospital treatment. This is done by a specialized, multidisciplinary trauma team consisting of a group of individuals from various specialties including anaesthesia, emergency medicine, surgery, nursing and support staff.\(^22,23\)

Recent developments in prehospital telemedicine have heightened the enormous potential in acute myocardial infarction (AMI) and stroke.\(^24,25\) Telemedical interventions may potentially have a beneficial effect on prehospital treatment and in-hospital procedures,\(^26,27\) especially in the context of EMS with their limitations in diagnostic and therapeutic equipment at emergency site.

Telemedicine has been defined as the remote exchange of medical data via information and communication technologies (ICT) to improve a patient’s clinical health status. This includes interactive consultative and diagnostic services. Telemedicine applications connect patients directly to health care providers and employ asynchronous (store and forward), synchronous (real time) or a combination of both.\(^28\) With the increased use of ICT in healthcare, there has been a great emphasis on telemedicine because it can extend the services of providers to remote locations and capitalize on the availability of subject matter authorities and surmount the barrier of proximity. Due to variation of telemedicine service reimbursement, privacy apprehensions, questions concerning the economic viability, logistics and absence of medical evidence, the acceptability of telehealth into routine care is still poor.\(^29–31\)

Telemedicine in acute and critical care is integrated in two different models: Hub (providing telemedicine services) and Spoke (receiving telemedicine services).\(^32\) Drip (first adminis-
Data Sources and Searches
Articles were identified by electronic bibliographic database search using keywords related to prehospital setting, ambulance, telemedicine, and (major) trauma with Boolean operators AND/OR. Thus, the search (►Online Appendix 1) in this review was conducted using the following combinations of terms (Mesh terms): (1) ambulance, telemedicine, trauma and (2) prehospital, telemedicine, injury OR trauma.

In brief, two reviewers (PE and BR) independently searched electronic databases including PubMed (via MEDLINE), Excerpta Medica Database (EMBASE), the Cochrane Library (via Wiley), Cumulative Index to Nursing and Allied Health Literature (CINAHL via EBSCOhost), SpringerLink (Springer Nature), LIVIVO, Database of Abstracts of Reviews of Effects (DARE), IEEE Xplore, ScienceDirect (Elsevier). We included citations from January 1995 onwards to December 2015, with updates until March 2018. We decided to restrict our search at 1995 as the types of telehealth services under consideration commenced operation around this time. In addition, Google Scholar was searched to trace grey literature. Measurement of inter-rater reliability was not recorded. References of reviews were included as well.

Initial screening of the identified articles was based on their abstracts and headlines. The references to the relevant literature were searched by hand for matching articles (reference tracking). In addition, we hand searched two key journals: i) Journal of Telemedicine and Telecare as well as the ii) International Journal of Telemedicine and Applications.

Study Selection
All included studies meet the PRISMA statement criteria. In September 2015, we defined the methodology based on the PRISMA checklist (►Online Appendix 2) in an a priori established review protocol (unpublished). The protocol for this review was not registered. A flow diagram of the literature search results is presented in ►Fig. 1. Inclusion (PICOS: patient, intervention, comparator, outcome, study design), and exclusion criteria were also planned prospectively. We expanded the PICO template by the “S” for study design to identify relevant articles and select articles more specifically. The exclusion criteria were: i) the paper was only available in form of an abstract or poster, ii) the paper was not peer-reviewed, iii) the paper was a qualitative study, case report, editorial, dissertation, protocol paper or review, iv) the paper included telemedical applications connecting hospitals. Thereafter, we assessed the preselected items according to the criteria of the PICOS template (see ►Table 1) and their suitability about the issue. In addition, we included studies that compared a telemedicine application with a conventional alternative.

![Fig. 1 Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA 2009) flow diagram.](Methods of Information in Medicine)
Studies without control group were included by rater consent. After an initial screening, we extended the exclusion criteria with combat and military actions and included civilian trauma only and we also decided to include simulated scenarios on manikins as well. Further restrictions did not apply, because we assume that telemade management in prehospital environment to consist of complex interventions.

Eligibility Criteria
All searches conducted in this review were restricted to English. Two authors (PE and BR) independently assessed studies for eligibility. We thoroughly discussed and resolved discrepancies by consensus. We checked the screened articles for their eligibility and imported them into a bibliographical database library (EndNote X8.2), respectively. Duplicate citations were removed manually.

Data Extraction
One reviewer (PE) performed data extraction in a standardized form, while another reviewer (BR) randomly checked the data extraction. We extracted the following data: authors, year of publication, characteristics of the study population and methodology, study results according to the prehospital telemedicine of trauma patients, and nature of telemedical approach. We additionally extracted mortality rates, treatment times, the length of stay in hospital and adverse effects. We defined adverse events as harmful results, recurring from technical problems while performing telemedicine in acute trauma care. However, this systematic review does not have a hypothesis testing approach, so that including this restriction in choice of outcomes is not necessary.

Data Synthesis and Critical Appraisal
Preliminary synthesis was done by tabulation, groupings and clusters (see Table 2) and textual description of main findings. We scrutinized the rationale of the telemedical intervention and intended to provide a descriptive account of the main recurring themes. The investigation of heterogeneity was determined by authors’ assessment of the studies’ methodology. Risk of bias was not assessed due to heterogeneity of study designs. Instead, we conducted the classification of included studies using the Levels of Evidence (LoE) of Oxford Centre for Evidence-based Medicine.

Results
Our systematic review of the literature identified n = 1430 potentially relevant citations. After manually removing duplicates and studies assessing stroke, acute myocardial infarction or other non-trauma diagnoses, 398 unique citations remained to be reviewed. We excluded 323 citations using standardized predetermined selection criteria based on manuscript title and abstract. Out of the remaining 75 full text articles, we excluded 60 articles which did not meet the PICOS template. 15 articles were considered to represent assessment studies fulfilling the inclusion criteria of

Table 1 Study eligibility criteria in terms of the PICOS template

<table>
<thead>
<tr>
<th>Patient</th>
<th>Severe trauma ISS ≤ 16 (involving several areas of the body, or single injury)</th>
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</thead>
<tbody>
<tr>
<td>Designation as trauma patient</td>
<td></td>
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<tr>
<td>Manikins, dummies</td>
<td></td>
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<tr>
<td>Intervention</td>
<td>Transferal of prehospital data with at least one telemedical application (digital image, video conference, audio, etc.) between ambulance and remote expertise</td>
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<tr>
<td>Comparator</td>
<td>Conservative / standard approach / usual care</td>
</tr>
<tr>
<td>Outcome</td>
<td>Mortality rate</td>
</tr>
<tr>
<td>Treatment times (in-hospital and prehospital)</td>
<td></td>
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<tr>
<td>Adverse effects</td>
<td></td>
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<tr>
<td>Study Design</td>
<td>Randomized controlled trial (RCT)</td>
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<tr>
<td>Observational study</td>
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<tr>
<td>Case-control study</td>
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<tr>
<td>Retrospective or prospective studies</td>
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<tr>
<td>Simulated scenario</td>
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Table 2 Description of generic key components of prehospital telemedicine in acute trauma care

<table>
<thead>
<tr>
<th>Telemade components</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recording and transmission of key vital signs</td>
<td>Monitors/defibrillators, 12-lead ECG devices, ventilators and video laryngoscope provide vital parameters (e.g. electrocardiogram, oxygen saturation, heart rate) via wireless connection (Bluetooth).</td>
</tr>
<tr>
<td>Video, audio, photo and text transmission of on-scene accident/emergency site and emergency department</td>
<td>Video communication via on-board camera, installed in the ambulance cabin with zoom and swivel function or a wearable portable head camera for mobile examinations.</td>
</tr>
<tr>
<td></td>
<td>Audio communication via headset or integrated microphone.</td>
</tr>
<tr>
<td></td>
<td>Remote workstation equipped with videoconferencing consultation system to control remote camera in ambulance.</td>
</tr>
<tr>
<td></td>
<td>In-ambulance mobile network system with appropriate bandwidth speed.</td>
</tr>
<tr>
<td></td>
<td>Mobile device to enter and store patient related data with compressed transmission of vital parameters and text messages.</td>
</tr>
<tr>
<td>Tele-Ultrasound</td>
<td>Detection of free abdominal fluids and review of ultra-sound images on-scene or en route.</td>
</tr>
</tbody>
</table>
PICOS template and included in narrative synthesis. We found the design characteristics of the included studies are clinically heterogeneous. Thus, it was not possible to aggregate the study results in a quantitative meta-analysis. Narrative analysis examined which telemedicine services in acute trauma care are implemented and describes the nature of intervention and what are the reported effects of telemedicine on acute trauma care by EMS. The table in Online Appendix 3 shows the summarized findings of the included studies.

Description of Included Studies

The 15 included articles were published between 2004 and 2017 and originated from countries USA (n = 3), Greece (n = 1), Germany (n = 5), Thailand (n = 1), Belgium (n = 1), South Korea (n = 2), Japan (n = 1) and Canada (n = 1), representing three continents (North America, Europe, Asia). In simulated studies (n = 6), a total of 109 trauma patients were conservatively managed by EMS, while 195 trauma patients with prehospital telemedicine intervention were reported. Simulated scenarios reported outcomes measured on manikins or dummies. Under real conditions (n = 9), a total of 1034 trauma patients were transported conservatively by EMS, and 423 trauma patients with prehospital telemedicine, respectively (see table in Online Appendix 3).

Characteristics of Telemedical Solutions

Telemedical solutions were reported in several terms: MTS (Mobile Telecommunication-System), TEP (Tele-EMS-physician), TMA (Telemedical Assistance), RTS (Real-Time-Telemetry-System), TPN (Telemedical Prenotification) and TUS (Tele-Ultrasound).

MTS is a general term in ICT and describes the characteristics of the hardware components to be mobile. Ambulances are equipped with ICT to stay in contact while driving or acting on-scene.

TEP is a physician or technologist at a central workstation linked to a telemedicine-equipped ambulance providing real-time audio and visual communication during patient transport and treatment.63–65 It describes the characteristics of the structure and the personnel.

TMA describes the communication and action during an emergency medical incident between paramedics and a remote clinical expertise. Paramedics will get subsequently instructed by a consultant (via delegation of medical procedures) with the aid of a two-way interactive technology. In most studies, the ambulance is equipped with one or more cameras with zoom and swivel function. A bidirectional audio-visual communication connects on-scene personnel with additional microphones and sound systems or head-phones with a telemedicine workstation. The TEP receives the patient’s data on his PC and may gather further information via a monitor or speakers/headphones. Having evaluated the data, the TEP can give further instructions to on-scene paramedics. In addition to appropriate bandwidth speed, security, and reliability, equipment to conduct a proper video teleconferencing consult (VTC) requires either an add-on desktop hardware program or a dedicated system which is integrated with remote-controlled camera, control computer, TV monitor and microphone.66,67

RTS describes the continuous monitoring, recording, and managing of the patient’s vital signs which are synchronously shared with the TEP.68–70 RTS uses low-data-transmission-rate networks on satellite communications and cellular phone network. Still images and video are transmitted from the wireless cameras installed in the ambulance cabin, allowing the monitoring of the patient’s condition and the control of the crew’s actions. Viewing pictures enables the emergency practitioner’s decision making especially in terms of severe wounds to examine severity of tissue damage.68 In most cases, transmission of vital signs was conducted between the monitor–defibrillator unit or in-ambulance mobile cellular network and the telemedical workstation.63,66,71

TPN describes the communication between the ambulance and the receiving hospital. On the way to the hospital, the paramedic sends the patients’ data to ED which, in most cases, leads to an earlier coordination of all medical specialties. ED members initiate the diagnostic work-up plan before the EMS’ arrival.72 One advantage of telemedicine technology is the compressed transmission of vital parameters such as oxygen saturation, ECG, blood pressure, or respiratory rate and a text message.65 Communication of a prehospital report to the in-hospital team and prenotification of the in-hospital team was done via SMS.65 Just prior to leaving the site, paramedics transmit these data to the receiving ED as initial pre-arrival information.65,70,73,74

TUS describes the telemedical assistance and guidance in ultrasound examination of mostly untrained paramedics by remote specialist. In terms of trauma, TUS is used to detect fluid retention in the abdominal and thoracic cavities, and thus, to evaluate the urgency of treatment.74–76

Table 2 summarizes the generic key components of the telemedical concepts in prehospital trauma care and describes the technical solutions involved.

Simulations

Tele-Ultrasound was examined in three studies.74–76 Boniface et al. demonstrates that paramedics with no previous experience with ultrasound were enabled to perform focused assessment with sonography for trauma (FAST) examination after a very brief introduction when being instructed by TEP. The time from probe placement to examination completion is 262 seconds (IQR: 206–343 s) in simulated trauma scenarios.75 Song et al. evaluated a real-time prehospital ultrasound image transmission system for the use in focused assessment with FAST on simulated trauma scenarios.74 The sensitivity and specificity of prehospital ultrasound image interpretation were 90.0% (95% CI; [83.5–94.6]) and 85.3% (95% CI; [78.4–90.7]), respectively. The accuracy of detecting abnormal ultrasound results was 87.7% (95% CI; [83.8–91.6]).74 Kirkpatrick et al. conducted a simulated multicentre randomized controlled trial on an ultrasound phantom examined by completely inexperienced and remotely mentored fire-fighters to detect free fluids after trauma. RTS was used to share ultrasound images or videos from the scanner to connected fire fighters. Firefighters wearing a portable head camera were guided by a TEP through the
ultrasound examinations with the remotely mentored tele-US (RMTUS) system. There was an overall accuracy of 97% (95% CI; [91.6–99.4]) sensitivity of 94% (95% CI; [83–99]), and specificity of 100% (95% CI; [93–100]).

Telemedical Assistance was examined in three studies. Charash et al. improves recognition rates for key signs (pericardial tamponade; \( p = 0.001 \)), processes (administer i.v. fluid bolus; \( p = 0.01 \)), and critical interventions (thoracotomy and pericardiocentesis supervision) \( p < 0.001 \). Skorning et al. examined in controlled simulations, that TMA can support prenotification process and significantly reduce time till notification \( (547.33 \text{ vs. } 189.00 \text{ s}; \ p = 0.0001) \). TMA of on-scene EMS by TEP in emergency situations significantly reduced time from loss of consciousness to intubation \( (283.62 \pm 83.29 \text{ s} [212–299 \text{ s}] \text{ vs. } 389.77 \pm 125.53 \text{ s} [337–411 \text{ s}]; \ p = 0.0048) \).

**Non-randomized Controlled Studies**

Telemedical assistance can be efficient in cases where the emergency physician is absent on-scene. The duration of the teleconsultation can be considerably shorter than the time to ambulance normally needed by the emergency physician to arrive physically at the site, especially in rural areas. In case of a drug authorisation request, the paramedic can enter the drug request information and transmit it to the receiving TEP. Physicians at the ED or at the remote workstation would then transmit the authorisation to the requestor. The time between the application of appropriate doses of analgesic (opioid or ketamine) and anaesthetic (thiopental, etomidate or propofol) drugs in case of major trauma is shortened by telemedical intervention. The time from the beginning of teleconsultation to the completion of the teleconsultation protocol was faster in telemedicine group as in cases with on-scene EMS physician care \( (36.5 \pm 16.0 \text{ min (telemedicine) vs. } 41.3 \pm 17.9 \text{ min (control); } p = 0.01) \).

The study of Lenssen et al. found no significant difference in numerical reduction in NRS score between both groups \( (4.94 \pm 2.01 \text{ vs. } 4.84 \pm 2.28; \ p = 0.5379) \). Another prospective study with historically matched controls found, that TMA in acute trauma pain concerning the application of analgesics by paramedics in the telemedicine group is safe and leads to a pain reduction \( (3.78 \pm 2.0 \text{ vs. } 4.38 \pm 2.2 \text{ NRS points; } p = 0.0159) \).

By using TMA for medical direction, Cho et al. reduce the time on-scene \( (18 \text{ min vs. } 2 \text{ min; } p = 0.009) \). The study also showed that using the RTS significantly reduces the number of voice calls needed \( (p < 0.001) \). Kim et al. reduced treatment time on scene \( (4.6 \pm 3.6 \text{ vs. } 6.2 \pm 6.6; \ p = 0.008) \), as well as the calculated transport time \( (22.5 \pm 10.3 \text{ vs. } 16.4 \pm 9.9; \ p < 0.001) \) significantly for trauma patients. Vagianos et al. GPS tracked ambulances and blocked traffic lights in case of multiple injuries (car accidents) and reduced total transportation time significantly. Furthermore, the study of Kim et al. admits a slight improvement of vital parameters when using TMA at the site of accident in blood pressure \( (142.8–44.8 \text{ mmHg, } 135.3–26.1 \text{ mmHg; } p = 0.052) \) and oxygen saturation \( (95.8–9.0 \text{ SpO2, } 94.2–9.3 \text{ SpO2; } p = 0.060) \).

**Mortality, Length of Stay and Adverse Events**

One observational study shows no significant differences in length of stay \( (p = 0.824) \), mortality of operated patients \( (26.8\% \text{ vs. } 13.3\%; \ p = 0.293) \) and ED mortality of non-operated patients \( (7.8\% \text{ vs. } 11.1\%; \ p = 0.449) \). Liu et al. report a survival to discharge of 91% in prospective cohort. Charash et al. simulated study found a reduction in mortality from 100% to 8% \( (p < 0.001) \) with TEP intervention within two scenarios. Only four studies included detailed data on adverse effects or complications arising from telemedicine in acute trauma care. Lenssen reported one case in the telemedicine group with moderate hypotension after administering midazolam and ketamine, but no adverse effects occurred due to technical problems. Connection failure occurred in telemedical operations more often compared to voice calls via cellular phone \( (9\% \text{ vs. } 18.3\% \text{ vs. } 0.6\% \text{ vs. } 0.9\% \text{ vs. } 18.3\% \text{ vs. } 13.3\%) \). Cho et al. reported, that in 68.35% of the telemedicine cases cellular phones were concomitantly used to compensate the poor audio quality. Yperzeel et al. report a success rate 39 of 43 cases. Failures resulted from low bandwidth, low battery charge and initiation of safe mode.
Reliability of technical solutions were generally high and minor complications were reported. Furthermore, some studies stress the importance of intensive training and a continuous application of telemedicine training for the users to ensure smooth work processes and to guarantee a high level of treatment quality.

Discussion

We conducted a systematic review on out-of-hospital treatment of trauma patients transported by EMS with telemedical support compared to standard or conventional procedures. The present study is one of the few studies that systematically review the intervention evaluation studies in the field of prehospital trauma telemedicine. Telemedicine technologies, used in the individual studies, were described with differing exactness. Some studies point to previous research that describe the system in detail.

Principal Findings

Telemedical assistance and telemedical prenotification are the major modes for healthcare delivery in prehospital trauma care. These telemedical concepts relate to the connection of paramedics or emergency physicians to remote clinical expertise during an acute episode of prehospital trauma care. Delays in the prehospital period can be minimized using teleconsultation and initiating the emergency department protocols by telemedical prenotification, respectively.

Using video guidance, the TEP can delegate in- or non-invasive and legally restricted procedures such as cricothyroidotomy, siphon drainage, ultrasound examination or drug administration to the on-scene paramedics. This delegation enables the paramedics to perform the right procedure at the right time. Furthermore, it leads to a qualitatively higher recognition rate of critical vital parameters and handling of critical situations. Telemedical assistance of on-scene paramedics and emergency physicians by TEP seems to be a promising approach in case of a missing physician at scene or because of legal restrictions in performing medical procedures. The location of the TEP in most of the studies is a remote workstation, separate from the ED. This does not mean, that placing the TEP in other locations is less effective, but in the literature, they are underrepresented. When needed, the appearance of on-scene emergency physicians is mandatory and thus telemedicine does not replace a physician’s expertise and skills. In cases of mild trauma, supervision by TEP can lead to an improved allocation of emergency physicians and possibly reduce the frequency of emergency physicians’ consultation. It could be beneficial to locate the TEP in the ED, because he also can log on to the computer in hospital to access the clinical data and check the patients’ medical history.

The technical and organizational configurations of included telemedicine modalities is characterized by clearly demarcated roles (see Table 3).

After prehospital stabilization with TMA, time in transit can be used to consequently inform the in-hospital trauma team with standardised telemedical prenotification protocols and pave therapeutic itineraries. Current evidence of prenotification for major trauma patients reported a significant reduction in mortality (Odds Ratio [OR] 0.61; 1 study, n = 72073 patients) and a nonsignificant change (OR 0.61; 1 study, n = 81). Further research in the effect of prenotification in acute trauma care is ongoing.

Previous reviews in acute trauma care identified telemedical assistance by remote medical expertise as prominent telemedical modality and included mostly cases studies. These findings match those observed by Winburn et al., that the most used telemedical application in prehospital care was real-time video-conferencing. Rogers et al. included also four of the studies that were analysed in this review, but categorized them into general care. New to previous work is knowledge about different telemedical modes, the dissemination of trauma telemedicine, the technical reliability and further evidence.

Prehospital Telemedicine in Other Clinical Entities

Prehospital telemedicine plays a decisive role in improving the quality of health care services. Surprisingly, prehospital telemedicine in acute trauma was found to favour TMA by remote clinical expertise (TEP) for rural patients. Compared to other applications in prehospital telemedicine, e.g. in hyperacute stroke or AMI, prehospital telemedicine shows a variation upon the clinical focus. In case of AMI, prehospital triage and advanced prenotification was done with ECG telemetry, which nearly halved time to treatment in AMI and decreased mortality rates significantly. Telemedicine in AMI is evidence based on several randomized controlled trials (RCTs) and quantitatively aggregated into meta-analysis. However, in case of hyperacute stroke, some ambulances are equipped with telemedicine, point-of-care (POC) labs and computer tomography (CT) to perform on-scene brain imaging. Such mobile stroke units (MSU) may perform thrombolysis prehospitaly, recognize intracranial haemorrhage faster and reduce time to treatment significantly, but may not improve short-term functional outcomes and mortality. Prenotifying the receiving hospital about a patient with stroke being transported can facilitate earlier preparation of the CT and stroke unit team. Thus, it improves the treatment intervals and functional patient outcomes. Telemedicine in hyperacute stroke care is mainly based on observational studies and few RCTs. Compared to other clinical entities, in case of prehospital trauma telemedicine, there is still a need for explanatory and pragmatic outcome evaluation.

Implications for Practice and Implementation

Telemedicine may play an essential role in the acute phase, including assistance with triage, stabilization of vital signs, and coordination of medical logistics (medical direction). It is necessary to eliminate the previously repeatedly encountered technical problems and to ensure maximum quality of the data transfer and overcome clinical inertia. The reliability of telemedicine technology is an essential precondition for the telemedical supported supply of vitally endangered patients. Data transmitted while the ambulance
is in motion requires high technical standards. Especially in critical emergency situations, the technique should not cause additional problems, but must support patient care as best as possible, e.g. by redundancy of wireless service providers. In this review, tele-ultrasound was feasible in simulations, but a recent study from Becker et al. found prehospital tele-ultrasound in patients with respiratory distress to be not feasible under real-world conditions with currently available technologies (equipment failure occurred in 25%).

Telemedicine in acute trauma care are complex interventions and mostly innovative projects and involve reorganization of relevant health establishments. Telemedicine in ED and in EMS need to be collaborative components in the chain of survival. The geographical variation in regional concepts reveals that a telemedical system that may work successfully in one country may not be instantly extendable in other countries. Implementation of the presented telemedical components into routine care requires an iterative program of research with a systematic and rigorous approach and should be tailored to local conditions and laws.

Recommendations for Future Research
The following key challenges have been identified that impede further evidence synthesis in this body of literature. Despite the small sample sizes, limited number of included studies and slow diffusion in clinical routine, we believe that the potential benefit for patients suffering from acute trauma is more prominent then discoursed in literature. There was considerable variation and discrepancy in how the studies reported their findings. In this review on prehospital telemedicine in acute trauma care, numerous outcome measures used to report on these interventions and programs were identified. There is a need of homogeneous studies which share comparable outcome parameters, exacerbated by a lack of common terminology in telemedicine. Moreover, there are dissimilarities in included accident mechanisms and severity specification. Furthermore, the information was difficult to evaluate due to the heterogeneous nature of the population, differences in design, and measurement methods.

There are currently no standards on the dissemination of prehospital telemedicine, but the CONSORT-EHEALTH statement (Consolidated Standards of Reporting Trials of Electronic and Mobile HEA/lth Applications and onLine TeleHealth) improves reporting of study results and provides a basis for evaluating the validity and applicability of eHealth trials. In spite of difficulties to perform randomized controlled trials in prehospital emergency settings, further well-designed trials are still needed. Research issues of

| Table 3 Description and classification of telemedical concepts in prehospital trauma care |
|---------------------------------|---------------------------------|---------------------------------|
| **Telemmedical Configuration** | **Telemmedical Assistance**     | **Telemmedical Prenotification** |
| Characteristics of transmitted data | • Blood pressure
• Heart rate
• Oxygen saturation
• Blood sugar
• Body temperature
• Ultrasound images
• Electrocardiogram
• Prehospital diagnosis
• Scores
• Video
• Audio | • Text massages
• Blood pressure
• Heart rate
• Oxygen saturation
• Scores
• Patient demographics
• Prehospital diagnosis
• Electrocardiogram and automatic diagnostic operation
• Audio
• Photo of crash casualty and accident mechanism |
| Purpose of intervention | • Supervision and delegation of invasive procedures (e.g. intubation) and non-invasive procedures (ultrasound examination) where the emergency physician is absent on scene
• Improvement of recognition rate of pericardial tamponade, administration of 2nd i.v. application, fluid bolus, thoracostomy and pericardiocentesis | • Preparation of life-saving procedures and activating local protocols (e.g. transfusion of fresh-frozen plasma)
• Reduction of loss of information during clinical handover without increasing workload |
| Nature of intervention | • Guidance of essential procedures at a rural location where medical expertise is promptly needed
• Stabilization of vital signs at scene | • Prenotification allows an advanced coordination of resources and capacities between prehospital and hospital and provide enough time for in-hospital preparations |
| Modalities/direction of communication | • Bidirectional (hospital or central workstation to paramedic at emergency site)
• Real time (synchronous) | • Bidirectional (hospital or central workstation to paramedic at emergency site) or unidirectional (moving ambulance to hospital or central workstation)
• Real time (synchronous) or store-forward (asynchronous) |
future studies should focus on outcome parameters and provide an accurate definition of trauma of the included studies in terms of scores. Future evaluation should not only take mortality into account, but should also gauge functional outcomes and morbidity. Although some telemedicine has been published in peer-reviewed journals, the vast majority remain published in regional concepts.

Limitations and Strengths

The present review has several limitations. Although many different studies were identified, the major number of these studies were observational studies or simulated scenarios, which could limit the quality of the derived evidence. A significant bias in this review stems from the nature of telemedical approaches, heterogeneous study groups and designs found for screening. We did not assess bias across all studies, as the studies could not be compared due to heterogeneity of outcomes, differences in types of telemedical intervention performed and differences in study design. Beyond this, requirements on treatment workflows and legal conditions are extremely different. Extracted data (main findings) are mostly compounded with non-trauma cases which leads to biased estimate of treatment effects. By restricting our literature review to peer-reviewed literature in English language and excluded case reports, we may have missed articles on studies of interest. Additionally, we did not contact authors of studies to obtain (missing) data or unpublished trials. The review does not report on sources of funding for the individual studies included. Having excluded articles due to their study design (e.g. qualitative studies, case reports or feasibility studies), we cannot generalize our findings to all telemedical applications in acute trauma.

However, the search was conducted on several databases (including grey literature) and updated through a repeat search. The research is based on well-established databases commonly used in similar type of reviews. We controlled for inter-rater reliability through the initial focus study of the topic followed by several consensus meetings held along the iterative process. Other important factors such as logistics, education, and costs were not considered in this review. Telemedical devices and systems presented in this review seem practical and auspicious.

Further reviews should include a risk of bias assessment; e.g. ROBINS-I, ACROBAT-NRS or the RoB 2.0 tool. According to the PRISMA checklist (review protocol) seven of 27 items are not applicable (#12, #13, #15, #16, #19, #21, #23), which are explained by an absent of meta-analysis and a risk of bias assessment. Despite these limitations, this systematic review provides a comprehensive overview of the state of telemedicine in prehospital trauma care.

Role of the Funding Source

There was no funding source for this study. The corresponding author (PE) and senior authors (BR, AR) had full access to all the data. All authors had full responsibility for the decision to submit for publication.

Conclusion

To our knowledge there is no similar systematic review analysing prehospital telemedicine in acute trauma care. The studies included in this review show how telemedicine have been involved in a wide range of projects oriented towards practice improvement. We highlight, that there is currently tentative evidence for the effectiveness of telemedicine aimed at improving patients suffering an acute trauma. Telemedical prenotification and telemedical assistance are two accompanying concepts in prehospital trauma care, giving the trauma team the tools to treat and observe the injuries at accident site immediately, so advanced trauma care can begin and the patient is brought to the most appropriate destination for care. Several studies show positive effects, but they lack sufficient sample size, randomization and application in daily routine. Lacking evidence pertaining specifically to the traumatic populations exists, but the growing body of literature on telemedical applications is likely to extend to the out-of-hospital setting to learn more about the benefit of telemedicine in routine care.

List of Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>AED</td>
<td>accident and emergency department</td>
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<tr>
<td>AMI</td>
<td>acute myocardial infarction</td>
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<tr>
<td>DALYs</td>
<td>disability-adjusted life years</td>
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<tr>
<td>ED</td>
<td>emergency department</td>
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<tr>
<td>EMS</td>
<td>emergency medical service</td>
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<tr>
<td>ICT</td>
<td>information and communication technologies</td>
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<tr>
<td>ICU</td>
<td>intensive care unit</td>
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<tr>
<td>PICOS</td>
<td>patient, intervention, comparator, outcome, study design</td>
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<tr>
<td>RTS</td>
<td>real-time telemetry system</td>
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<tr>
<td>STEMI</td>
<td>ST-segment elevation myocardial infarction</td>
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<td>TEP</td>
<td>tele-emergency physician</td>
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<td>TMA</td>
<td>telemedical assistance</td>
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<td>TPN</td>
<td>telemedical prenotification</td>
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<td>TV</td>
<td>television</td>
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<tr>
<td>VTC</td>
<td>video teleconferencing</td>
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Authors’ Contribution

PE, BR, UK and AR initially planned the systematic review (SR). PE and BR conducted the SR. UK and LS initially planned and reviewed the emergency medicine background from a EMS perspective. PE and BR repeated electronic database research. AR, PE and LS performed a review of included studies. All included studies are analyzed by consensus. BR, TW, AR and PE were the major contributors in writing the manuscript. All authors edited and revised the manuscript.

Conflict of Interest

The authors declare that they have no competing interests.
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