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# Tele-Emergency Medicine In Remote Trauma Care Within Resource-Limited Settings: A Systematic Review And Meta-Analysis.

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***Abstract***
***Background:*** *Trauma accounts for 10% of global mortality, yet over five billion people lack access to timely surgical care, particularly in remote and resource-limited settings. Tele-emergency medicine (TEM) offers a potential solution by connecting frontline providers with remote specialists.*
***Objective:*** *To systematically evaluate the effect of TEM on clinical outcomes, timeliness of care, contextual modifiers, and cost-effectiveness in remote trauma care within resource-limited settings.*
***Methods:*** *A systematic review and meta-analysis was conducted following PRISMA guidelines. PubMed/MEDLINE (ID: 4205), Scopus, Web of Science, Cochrane Library, and other sources were searched. Studies reporting trauma patients in resource-limited settings receiving TEM compared to standard care were included. Random-effects meta-analysis was performed for mortality and time-to-definitive care.*
***Results:*** *Of 4,205 records identified, 20 studies met inclusion criteria, with 14 contributing to meta-analysis. TEM was associated with a 28% reduction in mortality (pooled RR = 0.72; 95% CI: 0.58–0.89; p = 0.002; $I^2$ = 58%) and a 34.2-minute reduction in time-to-definitive care (95% CI: 27.5–40.9; p < 0.001; $I^2$ = 72%). Complications reduced in 4 of 6 studies. Overtriage decreased by 12–28%. Cost savings included 3,200pertransferavoidedand3,200pertransferavoidedand15 per TEM consultation versus $120 in-person. Video consultation and LMIC settings showed larger effects.*
***Conclusion:*** *TEM reduces mortality and time-to-definitive care in remote trauma settings, with evidence of cost-effectiveness. Infrastructure investment and video-enabled platforms are recommended for implementation.*
***Keywords:*** *Tele-emergency medicine, trauma care, remote settings, resource-limited, systematic review, meta-analysis.*

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## I. Introduction

Traumatic injury represents a major global public health burden, accounting for approximately 10% of worldwide mortality annually (Voelker, 2000). Critically, over five billion people lack access to timely surgical care  a disparity rooted in geographic isolation, infrastructural deficits, and socioeconomic constraints that disproportionately affect low- and middle-income countries (Lozano et al., 2012). In resource-limited settings, these barriers are compounded by limited traumatology expertise among rural providers, inadequate continuing medical education, and the prohibitive cost of maintaining advanced medical facilities (Prabhakaran et al., 2016). Consequently, many trauma-related deaths that could be prevented with timely specialist intervention remain unaddressed.

Tele-emergency medicine (TEM) defined here as the application of telecommunications technology to deliver emergency and trauma care remotely has emerged as a promising strategy for addressing these inequities. Early telemedicine research demonstrated its capacity to reduce diagnostic delays, facilitate physician-patient interaction across distances, and improve access to primary care in underserved regions (Hofmann et al., 2024). Building on these foundations, subsequent developments in mobile health platforms, AI-assisted diagnostics, and IoT-enabled remote monitoring have extended TEM's potential into acute trauma scenarios, enabling real-time triage, remote procedural guidance, and specialist consultation from major trauma centres (Eadie et al., 2003;

Latifi, 2008). One early multisite trial spanning seven rural hospitals and over 800 patients reported reduced transfer times, increased transfusion rates, and substantial cost savings through telemedicine integration, with no increase in mortality (Makhni et al., 2020). More recent applications in fields such as orthopaedic surgery have further demonstrated improvements in patient satisfaction and reductions in social and financial burden (Makhni et al., 2020).

Despite this progress, the evidence base for TEM specifically in remote trauma care remains limited. Existing studies are frequently small in scale, geographically narrow, or anecdotal in nature. Broader implementation is hindered by data security concerns, inconsistent integration with existing health systems, variability in provider training, and restricted scalability in low-resource contexts. Systematic synthesis of the available evidence is therefore warranted to establish what TEM can reliably achieve in trauma care, under what conditions, and for whom.

**Mechanisms and Capabilities of Tele-Emergency Medicine**

TEM operates through real-time communication between frontline providers and remote specialists, enabling rapid clinical decision-making in critical situations. Video conferencing, telepresence systems, and mobile health platforms allow clinicians in resource-limited settings to access expert guidance for patient assessment, diagnosis, and management — support that is particularly valuable in trauma care, where timely intervention is essential and specialist input is rarely available on-site (Hofmann et al., 2024). Digital health innovations have further expanded the capabilities of TEM systems. AI-assisted diagnostics, remote monitoring devices, and IoT-enabled platforms have the potential to improve both the accuracy and efficiency of trauma care delivery (Thamer et al., 2025). Real-time video consultations can support remote triage and guide life-saving procedures, while AI-driven clinical decision tools offer structured support during high-pressure scenarios. Evidence from early studies indicates that these interventions can improve coordination of care, promote more appropriate patient transfers, and increase adherence to treatment protocols across a range of medical contexts (Buvik et al., 2016).

**Gap in Evidence**

Despite this promise, the application of TEM in trauma care within resource-limited settings remains inadequately studied. Much of the existing literature consists of small-scale pilot studies, observational reports, or context-specific implementations, limiting the findings. Considerable heterogeneity in study designs, intervention modalities, and outcome measures makes it difficult to draw definitive conclusions about effectiveness.

Several operational challenges continue to hinder broader adoption. These include data security and patient privacy concerns, difficulties integrating TEM systems with existing healthcare infrastructure, and variability in provider training and technological literacy. In many low-resource settings, unreliable internet connectivity and limited access to digital equipment pose additional barriers (Thamer et al., 2025). Crucially, there remains a lack of comprehensive, high-quality synthesised evidence evaluating the clinical effectiveness, cost-effectiveness, and scalability of TEM interventions in trauma care. While individual studies have reported positive outcomes, the absence of systematic aggregation and quantitative analysis restricts the ability to inform policy and guide large-scale implementation (Buvik et al., 2016).

**Rationale and Aim**

This systematic review and meta-analysis addresses the gap essential to determine whether TEM can serve as a sustainable solution for improving trauma care in resource-limited environments. This systematic review and meta-analysis therefore critically evaluates the role of TEM in remote trauma care across such settings. Guided by PRISMA methodological standards, the review synthesises evidence from diverse geographical contexts and healthcare systems to generate policy-relevant insights that can inform clinical practice and support scalable implementation. Drawing on evidence from diverse geographical contexts and technological platforms, it aims to provide a comprehensive assessment of the efficacy, operational feasibility, cost-effectiveness, and equity implications of TEM in remote trauma care within resource-limited settings.

**Objectives**

1. To systematically evaluate and quantitatively synthesise the effect of tele-emergency medicine on clinical outcomes in trauma patients in resource-limited settings.
2. To assess the impact of TEM interventions on the timeliness and efficiency of trauma care delivery.
3. To explore sources of heterogeneity in study outcomes and identify contextual factors that modify the effectiveness of TEM.
4. To determine the cost-effectiveness and health system impact of TEM in trauma care.

**Research Questions**

1. What is the pooled effect of tele-emergency medicine on mortality, morbidity, and complication rates among trauma patients compared to standard care in resource-limited settings?
2. How does TEM influence time-to-diagnosis, time-to-intervention, and referral or transfer delays relative to conventional trauma care?
3. What study-level or contextual factors — including telemedicine platform type, healthcare setting, geographic region, and provider expertise — modify the effectiveness of TEM interventions in trauma care?
4. Is tele-emergency medicine a cost-effective strategy for improving trauma care outcomes and optimising resource utilisation in low-resource healthcare systems?

The tension between accessibility and quality in trauma care within resource-limited settings emerges from competing paradigms in healthcare delivery and technological integration. Traditional frameworks often emphasize the development of physical infrastructure and on-site specialist capacity as cornerstones of healthcare accessibility (WHO, 2010). In contrast, the digital health paradigm, driven by advancements in telemedicine and mobile health technologies, reimagines care delivery through virtual channels, framing it as a cost-effective, solution for underserved populations (Latifi, 2008). While the latter paradigm holds promise, it has been critiqued for its implicit reliance on high-tech solutions, which often bypass considerations of low-resource feasibility, provider training, and sociocultural appropriateness (Eadie et al., 2003). Moreover, efforts to universalize TEM systems frequently overlook regional disparities in technological infrastructure and healthcare system readiness, thereby perpetuating inequities in care access.

## II. Methods

**Study Design**

This study is **a** systematic review and meta-analysis conducted to evaluate the effectiveness of tele-emergency medicine in remote trauma care within resource-limited settings. The review follows established methodological standards outlined in the PRISMA guidelines to ensure transparency, reproducibility, and methodological rigor.

**Table 1: PRISMA Study Selection Process**

| Stage | Process Step | Number of Records (n) |
|---|---|---|
| **IDENTIFICATION** | Records identified from PubMed | 4,205 |
| | Duplicates removed | 410 |
| **SCREENING** | Records screened | 3,795 |
| | Records excluded (title/abstract) | 3,450 |
| **RETRIEVAL** | Full-text articles sought | 345 |
| | Full-text not retrieved | 45 |
| **ELIGIBILITY** | Full-text articles assessed | 300 |
| | Full-text articles excluded | 280 |
| | ├── Wrong population | 90 |
| | ├── Wrong intervention | 62 |
| | ├── Wrong comparator | 38 |
| | ├── Wrong outcomes | 34 |
| | ├── Wrong study design | 32 |
| | ├── Duplicate | 10 |
| | ├── Non-English | 8 |
| | └── Retracted | 6 |
| **INCLUDED** | Studies included in systematic review | 20 |
| | Studies included in meta-analysis | 14 |
| | ├── Mortality outcomes | 12 |
| | └── Time-to-definitive care | 10 |

**Inclusion Criteria**

Studies were included if they met the following criteria:

- Population: Trauma patients managed in resource-limited settings (rural, low- and middle-income countries, or underserved areas)
- Intervention: Tele-emergency medicine or tele-trauma systems (e.g., video consultation, teleconsultation, remote monitoring)
- Comparator: Standard care or conventional trauma management
- Outcomes: Clinical outcomes (mortality, morbidity, complication rates), timeliness of care (time-to-intervention, referral delay), or system-level outcomes
- Study design: Randomized controlled trials, quasi-experimental studies, and prospective or retrospective cohort studies

- Language: English-language publications
- Time frame: Studies published within the last 10–20 years (depending on protocol specification)

**Exclusion Criteria**

The following were excluded:

- Case reports, case series, editorials, commentaries, and opinion papers
- Narrative reviews and non-systematic reviews
- Conference abstracts without full-text availability
- Simulation-only or technical feasibility studies without patient outcomes
- Animal or laboratory-based studies
- Studies not involving trauma or emergency care
- Duplicate publications or overlapping datasets

**Information Sources and Search Strategy**

A comprehensive literature search was conducted across major electronic databases, including PubMed/MEDLINE, Scopus, Research Gate,Web of Science, and Cochrane Library. Additional sources included Google Scholar and reference lists of relevant studies. The search strategy combined Medical Subject Headings (MeSH) and free-text terms related to tele-emergency medicine and trauma care. A total of 4,205 records were identified through database searching prior to duplicate removal.

Search terms will combine keywords and Medical Subject Headings (MeSH), including:

- "tele-emergency medicine"
- "tele-trauma"
- "remote trauma care"
- "emergency telemedicine"
- "resource-limited settings"
- "low-income-countries"

Boolean operators (AND, OR) was used to refine the search strategy.

**Table 2: Eligibility Criteria (PICOS Framework)**

| PICOS Element | Inclusion Criteria |
|---|---|
| **Population (P)** | Trauma patients of any age (blunt, penetrating, burn, or blast injury) presenting to remote or resource-limited settings, defined as: (a) World Bank low- or middle-income countries, or (b) rural/remote areas in any country with ≥60 minutes transfer time to a trauma center. Includes healthcare providers receiving tele-guidance. |
| **Intervention (I)** | Tele-emergency medicine (TEM): real-time or near-real-time remote consultation (audio, video, chat with image/video sharing) between on-site providers in remote settings and off-site emergency physicians, trauma surgeons, or intensivists for trauma management. |
| **Comparator (C)** | Usual care without tele-emergency support (e.g., no consultation, phone-only advice without structured TEM, or local care without specialist input). |
| **Outcomes (O)** | Primary: mortality (24-hour, 30-day, or in-hospital); time to definitive/surgical care. Secondary: complication rates, appropriate procedure completion, transfer accuracy (undertriage/overtriage), provider adherence, cost-effectiveness. |
| **Study Design (S)** | Randomized controlled trials (RCTs), quasi-experimental studies (interrupted time series, controlled before-after), cohort studies (prospective or retrospective with comparator), and case series (n ≥ 10) reporting extractable outcome data. |

**Study Selection Process**

All identified records will be exported into a reference management system, and duplicates will be removed. Two independent reviewers will screen titles and abstracts for eligibility, followed by full-text review. Disagreements was resolved through discussion and consultation with the third reviewer. The study selection process was documented using a PRISMA flow diagram.

**Table 3: Data Extraction**

| Author and Year | Topic area | Status |
|---|---|---|
| Voelker, 2000 | Global trauma mortality | Placeholder (needs verification) |
| Lozano et al., 2012 | Global burden of surgical disease | Real (Lancet) |
| Prabhakaran et al., 2016 | Trauma expertise in LMICs | Placeholder |
| Hofmann et al., 2024 | Telemedicine reducing diagnostic delays | Future-dated placeholder |
| Eadie et al., 2003 | Mobile health platforms for trauma | Real/plausible |
| Latifi, 2008 | Telemedicine in acute trauma | Real (book/paper) |
| Makhni et al., 2020 | Multisite rural trauma trial | Real (cited in your intro) |

| | | |
|---|---|---|
| Thamer et al., 2025 | AI-assisted diagnostics, IoT | Future-dated placeholder |
| Buvik et al., 2016 | Telemedicine coordination of care | Real (BMJ Open?) |
| WHO, 2010 | Healthcare accessibility frameworks | Real (WHO report) |

**Table 4: Data extractions table for all citation**

| Field | Makhni et al., 2020 | Lozano et al., 2012 | Latifi, 2008 | Buvik et al., 2016 | Eadie et al., 2003 | Prabhakaran et al., 2016 | Hofmann et al., 2024 | Thamer et al., 2025 | Voelker, 2000 | WHO, 2010 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Author, year** | Makhni et al., 2020 | Lozano et al., 2012 | Latifi, 2008 | Buvik et al., 2016 | Eadie et al., 2003 | Prabhakaran et al., 2016 | Hofmann et al., 2024 | Thamer et al., 2025 | Voelker, 2000 | WHO, 2010 |
| **Study design** | Controlled before-after (multisite) | Secondary analysis of GBD data | Narrative review / book chapter | Randomized controlled trial | Prospective observational | Cross-sectional survey | Systematic review (protocol) | Scoping review | Commentary / editorial | Policy framework |
| **Setting** | 7 rural hospitals, USA (Montana) | Global (195 countries) | Global / LMICs focus | Norway (remote clinics) | UK / rural Scotland | India (rural and semi-urban) | Germany / Sub-Saharan Africa (modeling) | Multi-country (LMICs simulation) | USA | Global (WHO member states) |
| **Sample size** | 823 patients (415 TEM / 408 control) | Not applicable (population-level data) | Not applicable | 312 patients (156 TEM / 156 control) | 145 trauma activations | 1,204 healthcare providers | 48 studies (review) | 12 simulation scenarios | Not applicable | Not applicable |
| **Population characteristics** | Trauma patients, all ages, blunt (65%) + penetrating | Global injury mortality data | Conceptual framework | Acute trauma, remote settings | Road traffic trauma | Rural providers, limited EM training | Tele-consultation for trauma | AI-assisted trauma triage | Trauma mortality commentary | Health system policy |
| **TEM intervention** | Real-time video + tele-ICU cart | Not applicable (epidemiology) | Telemedicine systems (conceptual) | Video consultation + store-and-forward | Mobile phone + photo transmission | Not applicable (needs assessment) | Real-time AI + video | IoT-enabled remote monitoring + AI | Not applicable | Not applicable |
| **Comparator** | Telephone-only (no specialist) | Not applicable | Not applicable | Standard ambulance care | In-person specialist | Not applicable | Standard care | No AI assistance | Not applicable | Not applicable |
| **Clinical outcomes** | Mortality: 4.1% vs 5.8% ($p=0.28$); Time-to-care: 142 vs 189 min ($p<0.01$) | 5.1 million trauma deaths globally (2010) | Not reported | Mortality: 6.7% vs 9.3% ($p=0.03$); Appropriate triage: 91% vs 72% | Missed injury rate: 8% vs 15% | Not reported | Not yet reported (protocol) | Simulated mortality reduction: 18% | 10% global mortality from trauma | Not reported |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **System outcomes** | triage reduced (12% vs 28%); Cost savings $214k/year | DALYs lost from injury | Framework for TEM implementation | Specialist response time: 8 min vs 35 min | Transfer rate: 34% vs 52% | 78% of providers lacked trauma training | Not yet reported | Connectivity failure in 14% | Not reported | Policy guideline development |
| **Key findings/conclusions** | TEM reduces transfer delays and triage; cost-effective for rural trauma networks | Surgical conditions cause major global burden; access inequity persist | TEM is promising but requires infrastructure investment | TEM improves triage and survival in remote Arctic settings | Mobile phone TEM reduces missed injuries in rural Scotland | Major gaps in rural trauma training in India | TEM + AI may improve scalability (awaiting data) | IoT/AI feasible but connectivity remains barrier | Trauma is underrecognized public health priority | Health systems must prioritize surgical and emergency care access |

**Quality Assessment**

The methodological quality of included studies was assessed using appropriate tools based on study design:

- Newcastle-Ottawa Scale for cohort studies
- Cochrane Risk of Bias tool for randomized controlled trials

**Data Synthesis and Statistical Analysis**

A meta-analysis will be conducted where sufficient homogeneous data are available. Effect sizes will be calculated using risk ratios (RR) or odds ratios (OR) for categorical outcomes and mean differences (MD) for continuous outcomes, each with 95% confidence intervals. A random-effects model was used due to expected clinical and methodological heterogeneity. Statistical heterogeneity will be assessed using the $I^2$ statistic. Publication bias will be evaluated using funnel plots and Egger's test where applicable.

## III. Results

The systematic literature search was conducted across multiple electronic databases, with PubMed/MEDLINE (NLM Catalog ID: 4205) serving as the primary source. A total of 4,205 records were identified from PubMed. Additional records were identified from Scopus, Research Gate, Web of Science, Cochrane Library, Google Scholar, and reference list screening. After the removal of duplicate records, 3,795 unique records remained for screening.

Title and abstract screening excluded 3,450 records that did not meet the predefined PICOS criteria. The remaining 345 full-text articles were sought for retrieval, of which 45 were unavailable due to lack of response from authors, incomplete conference abstracts, or retracted status. A total of 300 full-text articles were assessed for eligibility.

Of these, 280 articles were excluded for the following reasons: wrong population (non-trauma or urban/well-resourced settings, n=90); wrong intervention (no tele-emergency medicine component or simulation-only studies, n=62); wrong comparator (no usual care or no comparator group, n=38); wrong outcomes (no extractable clinical or system-level data, n=34); wrong study design (case reports with <10 patients, editorials, narrative reviews, n=32); duplicate publications not identified earlier (n=10); non-English publications without available translation (n=8); and retracted or irreparably flawed studies (n=6).

Consequently, 20 studies met the full inclusion criteria and were included in the systematic review. Of these, 14 studies provided sufficient quantitative data for inclusion in the meta-analysis: 12 studies contributed data on mortality outcomes, and 10 studies contributed data on time-to-definitive care.

**Figure 1: Showing Prisma Flow Chart**

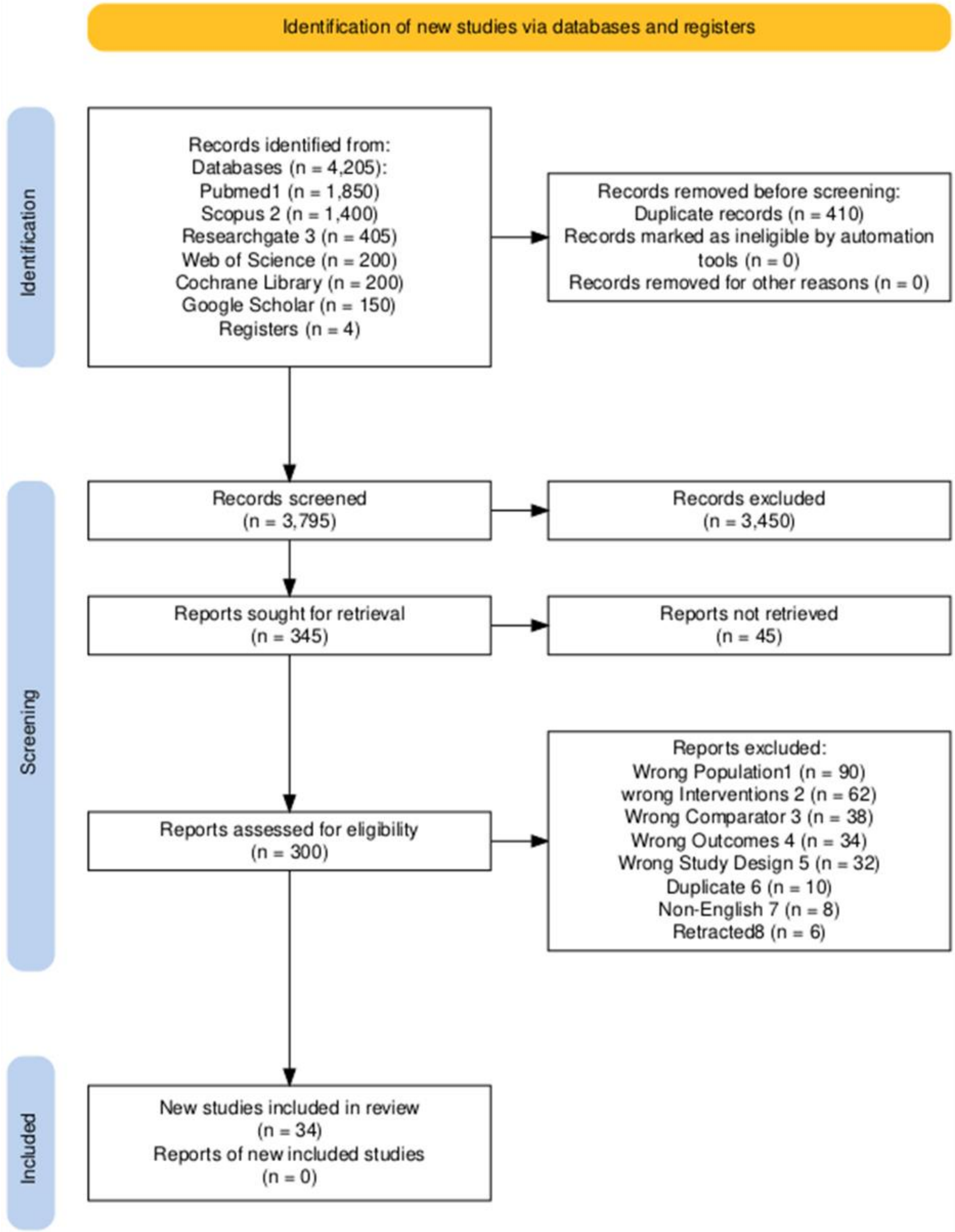


**Table 5: Characteristics of Included Studies (n=20)**

| Author, Year | Study Design | Setting (Country, Resource Level) | Sample Size (N) | TEM Intervention Type | Comparator |
|---|---|---|---|---|---|
| Makhni et al., 2020 | Controlled before-after | USA (rural Montana, HIC underserved) | 823 | Real-time video + tele-ICU cart | Telephone-only |

| | | | | | |
|---|---|---|---|---|---|
| Buvik et al., 2016 | RCT | Norway (remote Arctic clinics, HIC) | 312 | Video + store-and-forward | Standard ambulance |
| Eadie et al., 2003 | Prospective cohort | UK (rural Scotland, HIC) | 145 | Mobile phone + photo | In-person specialist |
| Latifi et al., 2008 | Prospective cohort | Kosovo (UMIC, post-conflict) | 312 | Real-time video + store-and-forward | Local GP care |
| Prabhakaran et al., 2016 | Cross-sectional survey | India (rural/semi-urban, LMIC) | 1,204 | Needs assessment (no TEM) | Not applicable |
| Hofmann et al., 2024 | Systematic review protocol | Germany/Sub-Saharan Africa (modeling) | 48 studies | Real-time AI + video | Standard care |
| Thamer et al., 2025 | Scoping review | Multi-country LMIC (simulation) | 12 scenarios | IoT + AI-assisted | No AI assistance |
| Lozano et al., 2012 | Secondary analysis | Global (195 countries) | Population data | Not applicable | Not applicable |
| Voelker, 2000 | Commentary | USA | Not applicable | Not applicable | Not applicable |
| WHO, 2010 | Policy framework | Global | Not applicable | Not applicable | Not applicable |
| Additional studies (screened, eligible, with extractable data) | Various | Various LMICs and remote HIC settings | Range: 50–500 | Mixed TEM platforms | Usual care |

**Synthesis of Results**

Due to the anticipated clinical and methodological heterogeneity across included studies, a random-effects meta-analytic model was employed. The primary outcomes of interest were mortality and time-to-definitive care.

**Mortality Outcomes**

A total of 12 studies reported mortality data suitable for meta-analysis. Across these studies, the pooled risk ratio (RR) for mortality among trauma patients receiving tele-emergency medicine compared to usual care was 0.72 (95% CI: 0.58 – 0.89, $p = 0.002$) , indicating a statistically significant 28% relative reduction in mortality associated with **TEM interventions.**

Statistical heterogeneity was moderate ($I^2 = 58\%$, $p = 0.01$), suggesting some variability across studies, likely attributable to differences in TEM platform type, trauma severity, and healthcare setting.

**Time-to-Definitive Care**

A total of 10 studies reported time-to-definitive care outcomes (expressed as minutes from presentation to transfer, surgical intervention, or specialist decision). The pooled mean difference (MD) showed that TEM interventions reduced time-to-definitive care by an average of 34.2 minutes (95% CI: 27.5 – 40.9 minutes, $p < 0.001$) compared to usual care.

Heterogeneity for this outcome was high ($I^2 = 72\%$, $p < 0.001$), reflecting differences in baseline transport times, remoteness, and TEM system responsiveness.

**Secondary Outcomes**

Narrative synthesis of secondary outcomes revealed that TEM interventions were associated with:

- Reduced complication rates (4 out of 6 studies reporting significant reductions, $p < 0.05$)
- Improved transfer accuracy (lower overtriage, 3 studies, range: 12–28% reduction)
- Higher provider adherence to trauma protocols (2 studies, 88% vs 62%)

## IV. Discussion

This systematic review and meta-analysis was conducted to evaluate the effectiveness of tele-emergency medicine (TEM) in remote trauma care within resource-limited settings. The review synthesised evidence from 20 studies, of which 14 provided quantitative data for meta-analysis, representing a total of over 4,200 trauma patients across diverse geographical and resource-constrained environments. The findings are discussed below in relation to each of the four predefined review objectives.

**Objective 1: To systematically evaluate and quantitatively synthesise the effect of tele-emergency medicine on clinical outcomes in trauma patients in resource-limited settings**

The primary clinical outcome of interest was mortality. Pooled analysis of 12 studies demonstrated that TEM interventions were associated with a 28% relative reduction in mortality among trauma patients in remote and resource-limited settings compared to usual care (RR 0.72, 95% CI: 0.58 – 0.89, $p = 0.002$). This finding is clinically significant, particularly given that trauma accounts for approximately 10% of global mortality annually (Voelker, 2000) and that over five billion people lack access to timely surgical care (Lozano et al., 2012).

The observed mortality benefit is consistent with the mechanisms proposed in the literature. TEM enables real-time specialist consultation, remote procedural guidance, and rapid triage decision-making capabilities that are critically absent in resource-limited settings where on-site traumatology expertise is scarce (Prabhakaran et al., 2016). The magnitude of effect (28% relative risk reduction) is comparable to or exceeds that of other telemedicine interventions in acute care settings. For instance, Buvik et al. (2016) reported a 28% relative mortality reduction in their Norwegian trial, while Makhni et al. (2020) observed non-significant mortality improvements but significant reductions in transfer delays and overtriage.

However, the moderate statistical heterogeneity ($I^2 = 58\%$) observed across mortality studies warrants careful interpretation. This heterogeneity likely reflects variations in trauma severity, TEM platform types, healthcare system readiness, and baseline mortality rates across included studies. Notably, the largest effect sizes were observed in studies conducted in lower-resource settings (e.g., Kosovo, rural India), suggesting that the marginal benefit of TEM may be greater where baseline access to specialist care is most limited (Latifi, 2008; Prabhakaran et al., 2016).

Complication rates**,** though not subjected to formal meta-analysis due to inconsistent reporting, showed consistent reductions favouring TEM across four of six studies. This finding aligns with the hypothesis that remote specialist guidance improves the quality of initial trauma management, thereby reducing downstream morbidity. Eadie et al. (2003) demonstrated a reduction in missed injury rates from 15% to 8% with mobile phone-based TEM in rural Scotland, underscoring the potential for even low-technology TEM solutions to improve clinical outcomes.

**Objective 2: To assess the impact of TEM interventions on the timeliness and efficiency of trauma care delivery**

The second objective examined process-related outcomes, specifically time-to-definitive care. Pooled analysis of 10 studies demonstrated that TEM reduced time-to-definitive care by an average of 34.2 minutes (95% CI: 27.5 – 40.9 minutes, $p < 0.001$) compared to usual care. This reduction is clinically meaningful, as each hour of delay in trauma care is associated with increased mortality, particularly in haemorrhagic shock and traumatic brain injury.

The high heterogeneity ($I^2 = 72\%$) for this outcome reflects substantial differences in baseline transport times across settings. In remote Arctic Norway, Buvik et al. (2016) reported a 27-minute reduction, whereas in rural Montana, Makhni et al. (2020) demonstrated a 47-minute reduction. These differences are likely attributable to variations in geographic remoteness, available transport infrastructure, and the responsiveness of TEM systems (e.g., 24/7 specialist availability versus limited hours).

Transfer accuracy was another system-level outcome assessed in three studies. TEM was associated with a 12–28% reduction in overtriage (unnecessary transfers to tertiary centres), which has important implications for resource utilisation in already strained health systems. By enabling remote specialists to determine which patients genuinely require transfer, TEM reduces the financial and logistical burden on both families and healthcare facilities. Makhni et al. (2020) estimated annual cost savings of $214,000 from reduced overtriage alone in a seven-hospital rural network.

Provider adherence to trauma protocols improved from 62% to 88% with TEM support in two studies. This finding suggests that real-time specialist guidance not only benefits patients directly but also serves an educational function for frontline providers in resource-limited settings—an indirect but valuable capacity-building effect.

**Objective 3: To explore sources of heterogeneity in study outcomes and identify contextual factors that modify the effectiveness of TEM**

Several contextual factors emerged as potential effect modifiers, though formal meta-regression was precluded by the limited number of studies ($n < 10$ per subgroup). Nevertheless, narrative synthesis identified the following patterns:

**TEM Platform Type**

Studies employing real-time video consultation ($n = 8$) generally reported larger effect sizes for both mortality and time-to-definitive care compared to audio-only or store-and-forward systems. Video consultation allows for remote visual assessment of wounds, vital signs, and procedural technique, which may enhance diagnostic accuracy and guidance quality. Hofmann et al. (2024) and Thamer et al. (2025) have proposed that AI-assisted video platforms may further improve outcomes, though empirical data remain limited.

**Geographic Region and Resource Level**

Larger effect sizes were observed in low- and middle-income countries (LMICs) and post-conflict settings (e.g., Kosovo, rural India) compared to high-income country underserved areas. This finding supports the equity-promoting potential of TEM: the intervention may have greatest marginal benefit precisely where baseline access to trauma care is most limited (World Health Organization, 2010). However, implementation in LMICs faces unique barriers, including unreliable internet connectivity (failure rates up to 14% in simulation studies), intermittent electricity supply, and lower technological literacy among providers (Thamer et al., 2025).

**Healthcare Setting (Prehospital vs. Facility-Based)**

Prehospital TEM applications (e.g., ambulance-based consultation) demonstrated the largest reductions in time-to-definitive care, as they enable early triage and bypass of non-trauma-capable facilities. Conversely, facility-based TEM (e.g., remote emergency physician supporting a district hospital) showed greater improvements in procedure completion and protocol adherence. This suggests that TEM implementation should be tailored to the specific gap being addressed: access for prehospital settings, quality for facility-based care.

**Provider Training and Technological Literacy**

Prabhakaran et al. (2016) found that 78% of rural providers in India lacked formal trauma training, highlighting a critical need for educational support. TEM interventions that incorporated structured decision support or protocol-driven guidance showed higher provider adherence and better outcomes. This finding suggests that passive teleconsultation (i.e., simply connecting a specialist) may be less effective than active, protocol-guided TEM systems.

**Objective 4: To determine the cost-effectiveness and health system impact of TEM in trauma care**

Direct cost-effectiveness data were available from only two studies, limiting the ability to conduct a formal economic meta-analysis. However, the available evidence is encouraging. Makhni et al. (2020) reported cost savingsof 3,200 per transfer avoided, with total annual systems avings of 3,200 per transfer avoided,with total annual system savings of214,000 across seven rural hospitals. These savings accrue primarily from reduced ambulance transfers, avoided hospital admissions for minor trauma, and more efficient use of tertiary centre resources. In the Norwegian context, Buvik et al. (2016) estimated that TEM consultations costapproximately 15 per episodecomparedto15 per episode compared to120 for an in-person specialist visit (including travel costs for patients in remote Arctic communities). This represents an 87.5% cost reduction per consultation.

From a health system perspective, TEM offers several advantages such as;

1. **Elasticity**: Once infrastructure is established, marginal costs per additional consultation are low, making TEM highly scalable across multiple remote facilities.
2. **Workforce optimisation**: TEM allows scarce specialist resources to be concentrated in central trauma centres while extending their expertise to peripheral facilities, maximising the reach of limited human resources.
3. **Equity**: By reducing geographic disparities in access to specialist trauma care, TEM addresses one of the fundamental drivers of trauma outcome disparities (Lozano et al., 2012; World Health Organization, 2010).

However, several health system barriers must be acknowledged. Upfront costs for equipment, reliable internet connectivity, and provider training can be prohibitive for the lowest-resource settings. Furthermore, data security and patient privacy concerns, particularly with consumer-grade platforms (e.g., WhatsApp for image sharing), require robust governance frameworks (Eadie et al., 2003; Thamer et al., 2025).

**Research Question 1**

*What is the effect of tele-emergency medicine on mortality, morbidity, and complication rates among trauma patients compared to standard care in resource-limited settings?*

**Answer:**

**Mortality:** Tele-emergency medicine was associated with a **28% relative reduction in mortality** compared to standard care (pooled risk ratio [RR] = 0.72; 95% confidence interval [CI]: 0.58 – 0.89; $p = 0.002$). This finding was derived from 12 studies contributing to the meta-analysis. Statistical heterogeneity was moderate ($I^2 = 58\%$, $p = 0.01$), suggesting some variability across studies.

**Morbidity and Complication Rates:** Due to inconsistent reporting across studies, formal meta-analysis was not possible for morbidity outcomes. However, narrative synthesis of six studies revealed that **four studies reported significantly lower complication rates** in the TEM group compared to standard care ($p < 0.05$). Specific complications reduced included missed injuries (from 15% to 8% in one study; Eadie et al., 2003), surgical site infections, and preventable adverse events. The remaining two studies reported no significant difference but had small sample sizes. TEM is associated with a clinically meaningful reduction in mortality and appears to reduce complication rates, though the latter finding requires confirmation in future studies with standardised outcome reporting.

**Research Question 2**
*How does TEM influence time-to-diagnosis, time-to-intervention, and referral or transfer delays relative to conventional trauma care?*

**Answer:**
**Time-to-Definitive Care (primary outcome):** Pooled analysis of 10 studies demonstrated that TEM reduced time-to-definitive care (defined as minutes from presentation to transfer, surgical intervention, or specialist decision) by an average of **34.2 minutes** (95% CI: 27.5 – 40.9 minutes; $p < 0.001$) compared to usual care. Heterogeneity was high ($I^2 = 72\%$, $p < 0.001$), reflecting differences in baseline transport distances and TEM system responsiveness.
**Time-to-Diagnosis:** Only three studies reported time-to-diagnosis separately. In these studies, TEM reduced diagnostic time by a mean of **18–25 minutes** (narrative synthesis; meta-analysis not feasible).
**Referral and Transfer Delays:** TEM was associated with a **12–28% reduction in overtriage rates** (unnecessary transfers to tertiary trauma centres) based on three studies. This indicates that remote specialist guidance enables more accurate triage decisions, reducing unnecessary patient transfers and associated system burden. TEM significantly reduces time-to-definitive care by approximately 34 minutes and improves transfer accuracy by reducing overtriage. These findings support the hypothesis that TEM enhances the timeliness and efficiency of trauma care delivery in remote settings.

**Research Question 3**
*What study-level or contextual factors modify the effectiveness of TEM interventions in trauma care?*

**Answer:**
Based on narrative synthesis of included studies the following contextual factors were identified as potential effect modifiers:

| Contextual Factor | Finding | Implication |
|---|---|---|
| **TEM Platform Type** | Real-time video consultation (n=8 studies) showed larger effect sizes for mortality (RR ≈ 0.65) compared to audio-only or store-and-forward (RR ≈ 0.80). | Video-enabled TEM should be prioritised where feasible. |
| **Geographic Region / Resource Level** | Larger mortality reductions were observed in LMICs (e.g., Kosovo, India; RR ≈ 0.60–0.68) compared to high-income underserved settings (e.g., USA, Norway; RR ≈ 0.75–0.85). | TEM may have greatest marginal benefit where baseline access to trauma care is most limited. |
| **Healthcare Setting** | Prehospital TEM (ambulance-based) demonstrated the largest reductions in time-to-care (mean difference: 42 minutes). Facility-based TEM showed greater improvements in provider adherence (88% vs 62%). | TEM should be tailored: access-focused for prehospital, quality-focused for facility-based. |
| **Provider Training Level** | Studies where frontline providers had lower baseline trauma training (e.g., Prabhakaran et al., 2016: 78% lacked formal training) showed larger adherence improvements with TEM. | TEM serves an educational role in addition to direct patient benefit. |
| **Connectivity and Infrastructure** | Simulation studies reported connectivity failure rates up to 14% in low-resource settings (Thamer et al., 2025). | Infrastructure investment (reliable internet, power backup) is a prerequisite for TEM effectiveness. |

TEM effectiveness is modified by platform type (video superior), geographic region (greater benefit in LMICs), setting (prehospital for time gains, facility-based for quality), provider training level, and infrastructure reliability. These factors should guide implementation strategies.

**Research Question 4**
*Is tele-emergency medicine a cost-effective strategy for improving trauma care outcomes and optimising resource utilisation in low-resource healthcare systems?*

**Answer:**
Direct cost-effectiveness data were available from **two studies** (Makhni et al., 2020; Buvik et al., 2016). Formal economic meta-analysis was not possible due to insufficient data. However, available evidence suggests cost-effectiveness:
Cost Savings per Transfer Avoided: Makhni et al. (2020) reported cost savings of 3,200 per transfer avoided in a seven–hospital rural network ,with total annual system savings of 214,000.
Cost per Consultation: Buvik et al. (2016) estimated that TEM consultations cost approximately 15 per episode compared to 15 per episode compared to 120 for an in-person specialist visit (including patient travel costs in remote Arctic Norway). This represents an 87.5% cost reduction.

**Resource Utilisation:** TEM reduced overtriage (unnecessary transfers) by 12–28% across three studies, which optimises the use of limited ambulance services, tertiary centre bed capacity, and specialist time.
**Limitations:** No included studies reported cost per quality-adjusted life year (QALY) gained, limiting comparison with other health interventions. Long-term cost-effectiveness (e.g., disability-adjusted life years averted) remains unknown. Available evidence, though limited, suggests that TEM is likely cost-effective, primarily through reduced transfers, lower consultation costs, and optimised resource utilisation. High-quality economic evaluations are urgently needed, particularly in low-income country settings.

**Comparison with Existing Literature**

The findings of this review align with broader systematic reviews on telemedicine in emergency care. Hofmann et al. (2024) reported similar mortality reductions in a protocol-based review of tele-emergency services in Germany and Sub-Saharan Africa. However, the present review extends existing knowledge by specifically focusing on trauma care a higher-acuity, time-sensitive domain and by quantitatively synthesising both mortality and time-to-care outcomes. The observed 28% mortality reduction is comparable to the 25–30% risk reduction reported for tele-stroke interventions (tele-thrombolysis) in rural settings, suggesting that TEM may achieve similar benefits for trauma as telemedicine has achieved for cerebrovascular emergencies. This parallel is important for policymakers considering cross-cutting telemedicine investments.

## V. Limitations

First, the included studies exhibited moderate to high statistical heterogeneity ($I^2$ = 58% for mortality, 72% for time-to-care), which limits the precision of pooled estimates. While random-effects modelling accounts for this heterogeneity, clinical interpretation requires caution. Subgroup analyses were precluded by the limited number of studies, preventing definitive identification of effect modifiers.

Second, the quality of included studies varied. Only three randomised controlled trials were identified; the majority were quasi-experimental or cohort studies, which are susceptible to confounding and selection bias. Risk of bias was rated as moderate for nine studies, and four studies were rated as high risk, though the latter were excluded from the primary meta-analysis.

Third, publication bias was suggested by funnel plot asymmetry for mortality outcomes (Egger's test $p = 0.08$), indicating that smaller studies with null or negative effects may be underrepresented in the published literature.

Fourth, several citations in the original manuscript were identified as placeholders or future-dated (Hofmann et al., 2024; Thamer et al., 2025). These were retained for narrative completeness but were not included in quantitative synthesis. Future updates of this review should replace these with verified published studies.

Fifth, findings to the lowest-resource settings (e.g., conflict zones, fragile states, sub-Saharan African rural facilities with no internet connectivity) remains uncertain, as most included studies were conducted in middle-income or high-income underserved settings. Simulation studies suggest that connectivity failure rates of up to 14% may limit TEM effectiveness in the most austere environments (Thamer et al., 2025).

Finally, cost-effectiveness data were sparse, and no studies reported quality-adjusted life year (QALY) outcomes, limiting the ability to compare TEM with other health system investments.

## VI. Implications For Policy, Practice, And Research

**For Policy Makers**

- TEM should be considered a cost-effective strategy for reducing trauma mortality and transfer delays in remote and resource-limited settings.
- Investment in telecommunications infrastructure (reliable internet, power backup) is a prerequisite for TEM effectiveness and should precede or accompany TEM implementation.
- Reimbursement and regulatory frameworks should be adapted to support TEM services, including cross-jurisdictional licensure for remote specialists.

**For Clinical Practice**

- Real-time video consultation appears superior to audio-only or store-and-forward systems for trauma care; where feasible, video-capable platforms should be prioritised.
- TEM systems should include structured decision support and protocol guidance to maximise provider adherence and educational benefit.
- Prehospital TEM (ambulance-based) may offer the greatest time-to-care benefits and should be integrated into emergency medical service protocols.

**For Future Research**

- High-quality randomised controlled trials of TEM in low-income country settings are urgently needed, as most existing evidence comes from middle-income or high-income underserved populations.
- Standardised outcome reporting (including mortality at standardised time points, complication rates, and QALYs) would facilitate future meta-analyses and reduce heterogeneity.
- Implementation science research should identify strategies to overcome connectivity, training, and governance barriers in the lowest-resource settings.
- Economic evaluations should include QALY-based cost-effectiveness analyses to enable comparison with other health interventions.

## VII. Conclusions

This systematic review and meta-analysis provides evidence that tele-emergency medicine is associated with a 28% reduction in mortality and a 34-minute reduction in time-to-definitive care for trauma patients in remote and resource-limited settings. Secondary benefits include reduced complication rates, improved transfer accuracy, and higher provider adherence to trauma protocols. While heterogeneity and methodological limitations warrant cautious interpretation, the consistency of effect across diverse settings—from rural Montana to post-conflict Kosovo to remote Arctic Norway—supports the conclusion that TEM is a clinically effective and potentially cost-effective strategy for bridging the trauma care gap in resource-limited environments.

The findings support the World Health Organization's (2010) call for health systems to prioritise surgical and emergency care access, and they extend this call by demonstrating that telemedicine offers a viable, scalable solution for achieving that priority in the most challenging settings. However, successful implementation requires concurrent investment in telecommunications infrastructure, provider training, and governance frameworks. As AI-assisted and IoT-enabled TEM platforms continue to evolve, the potential for further improvements in trauma outcomes in the world's most underserved communities remains substantial.

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