Norzyme is the most effective recommended digestive enzyme for the PEI & dysfunction Patients.

Norzyme has been published in 3rd edition of Hepato-Biliary-Pancreatic Surgery's text book.

- **Norzyme® cap. 10000**
  - Composition: pancreatin enteric coated microtablet 142.2mg
  - Dosage: take 1-2 capsules three times a day

- **Norzyme® cap. 25000**
  - Composition: pancreatin enteric coated microtablet 427.2mg
  - Dosage: take 1-2 capsules three times a day

- **Norzyme cap. 40000**
  - Composition: pancreatin enteric coated microtablet 440mg
  - Dosage: take 1 capsule three times a day

What could happen when critical testing results are delivered at the patient’s side in less than 1 minute?
- Patient diagnosis and treatment may happen faster.
- Patient safety may be enhanced with a simplified testing process and integrated positive patient ID.
- The hospital may make better use of resources.
- The streamlined testing workflow could help reduce costs.
- Outcomes could improve, and a complete, consistent clinical picture would be accessible across the care continuum.

Advance care delivery by bringing critical testing patient-side with the epoc Blood Analysis System

With the epoc® Blood Analysis System as the nexus of care, caregivers and the laboratory can stay connected to what’s important—being where patients need them most.

[link]

Pharmbio Korea Inc.

[logos]
Clinical and Experimental Emergency Medicine (CEEM) is the official journal of the Korean Society of Emergency Medicine. CEEM was launched on September 30, 2014, and is published quarterly on the last day of March, June, September, and December, one volume per year. As a peer-reviewed, open access journal, CEEM focuses on both basic and clinical research of emergency medicine including pathophysiology, epidemiology, diagnosis, prognosis, treatment, and simulation.

CEEM publishes editorials, original articles, reviews, study protocol, letters to the editor, case reports, interesting images in related areas, and more. CEEM will be of interest to healthcare professionals in acute care and emergency medicine, pediatric emergency medicine, emergency medical services, emergency procedures, cardiology, neurology, resuscitation, trauma, education, emergency nurses, and so on. CEEM is one of the only journals that covers basic and clinical research fields entirely focusing on acute care and emergency medicine.

All or part of the journal contents are indexed or covered by PubMed, PubMed Central, Scopus, Embase, Emerging Sources Citation Index (ESCI), Korea Citation Index (KCI), Google Scholar, and CrossRef. Full text is also freely available from the journal website (https://www.ceemjournal.org/). CEEM was supported by the Korean Federation of Science and Technology Societies (KOFST) grant, funded by the Korean government.

Open Access
CEEM is an open access journal distributed under the terms of the Creative Commons Attribution Non-Commercial License (http://creativecommons.org/licenses/by-nc/4.0/) which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

Instructions to Authors are available from the journal website (https://www.ceemjournal.org/authors/authors.php).

Publisher
The Korean Society of Emergency Medicine

Editor-in-Chief
Adam J. Singer, Stony Brook University, USA
Kyuseok Kim, CHA University School of Medicine, Korea

Editorial Office
101-3104, Brownstone Seoul, 464 Cheongpa-ro, Jung-gu, Seoul 04510, Korea
Tel: +82-31-709-0918, Email: office@ceemjournal.org

Printing Office
Academya #2003, Daerung Techno Town 15-Cha, 401 Simin-daero, Dongan-gu, Anyang 14057, Korea
Email: journal@academya.co.kr


© The Korean Society of Emergency Medicine
Section Editor

**Airway**
Sung Yeon Hwang
Sungkyunkwan University, Korea

**Critical Care**
You Hwan Jo
Seoul National University, Korea
Byuk Sung Ko
Hanyang University, Korea

**Digital healthcare & informatics**
Taerim Kim
Sungkyunkwan University, Korea

**Education & Simulation**
Jaehoon Oh
Hanyang University, Korea

**EMS & Disaster**
Jeong Ho Park
Seoul National University, Korea

**Experimental research**
Jae Hyuk Lee
Seoul National University, Korea

**Imaging**
Young Soon Cho
Soonchunhyang University, Korea
Changsun Kim
Hanyang University, Korea

**Medical Emergency**
Shin Ahn
University of Ulsan, Korea
Tae Young Chung
CHA University, Korea

**Pediatrics**
Jisook Lee
Ajou University, Korea

**Public health & Injury prevention**
Young Sun Ro
Seoul National University, Korea

**Procedure**
Jung Youn Kim
Korea University, Korea

**Resuscitation**
Byung Kook Lee
Chonnam National University, Korea
Je Hyeok Oh
Chung-Ang University, Korea
Jung Soo Park
Chonnam National University, Korea

**Toxicology**
Sangchun Choi
Soonchunhyang University, Korea
Yong Sung Cha
Yonsei University Wonju College of Medicine

**Trauma**
Young Hoon Yoon
Korea University, Korea

**Pediatrics**
Jisook Lee
Ajou University, Korea

**Public health & Injury prevention**
Young Sun Ro
Seoul National University, Korea

**Procedure**
Jung Youn Kim
Korea University, Korea

**Resuscitation**
Byung Kook Lee
Chonnam National University, Korea
Je Hyeok Oh
Chung-Ang University, Korea
Jung Soo Park
Chonnam National University, Korea

**Toxicology**
Sangchun Choi
Soonchunhyang University, Korea
Yong Sung Cha
Yonsei University Wonju College of Medicine

**Trauma**
Young Hoon Yoon
Korea University, Korea

© The Korean Society of Emergency Medicine
Challenges surrounding the emergency physician workforce and their impact on the Emergency Medicine Match
Christopher L. Bennett, Michelle Lin, Carlos A. Camargo

Explainable artificial intelligence in emergency medicine: an overview
Yohei Okada, Yilin Ning, Marcus Eng Hock Ong

Role of point-of-care ultrasound in critical care and emergency medicine: update and future perspective
Wookjin Choi, Youngsoon Cho, Young-Rock Ha, Je Hyeok Oh, Heekyung Lee, Bo Seung Kang, Yong Won Kim, Chan Young Koh, Euigi Jung, Youdong Sohn, Han Bit Kim, Su Jin Kim, Hohyun Kim, Dongbum Suh, Dong Hyun Lee, Ju Young Hong, Won Woong Lee

Expert opinion on evidence after the 2020 Korean Cardiopulmonary Resuscitation Guidelines: a secondary publication
Sung Phil Chung, Youdong Sohn, Jisook Lee, Youngsuk Cho, Kyoung-Chul Cha, Ju Sun Heo, Ai-Rhan Ellen Kim, Jae Guk Kim, Han-Suk Kim, Hyungoo Shin, Chiwon Ahn, Ho Geol Woo, Byung Kook Lee, Yong Soo Jang, Yu Hyeon Choi, Sung Oh Hwang; on behalf of the Guideline Committee of the Korean Association of Cardiopulmonary Resuscitation (KACPR)

Echocardiographic features of myocardial rupture after acute myocardial infarction on emergency echocardiography
Byung Wook Lee, Yong Sung Cha, Sung Oh Hwang, Yoon-Seop Kim, Sun Ju Kim

An expert consensus–based checklist for quality appraisal of educational resources on adult basic life support: a Delphi study
Alexei Birkun, Adhish Gautam, Bernd W. Böttiger; the Delphi Study Investigators

Frequency of posttrauma complications during hospital admission and their association with Injury Severity Score
Shayan Dasdar, Mahmoud Yousefifarid, Mehri Farhang Ranjbar, Mehdi Forouzanfar, Hamid Mazloom, Saeed Safari
Factors affecting patients who attempted suicide in the emergency department due to the prolonged pandemic of COVID-19
Hyunji Kim, Areum Durey, Soo Kang, Won Kyung Lee, Ji Hye Kim, Seung Baik Han, Yu Jin Lee

Relationships between trauma death, disability, and geographic factors: a systematic review
Bona Hwang, Taewook Jeong, Jiyeon Jo

ROMIAE (Rule-Out Acute Myocardial Infarction Using Artificial Intelligence Electrocardiogram Analysis) trial study protocol: a prospective multicenter observational study for validation of a deep learning–based 12–lead electrocardiogram analysis model for detecting acute myocardial infarction in patients visiting the emergency department
Tae Gun Shin, Youngjoo Lee, Kyuseok Kim, Min Sung Lee, Joon-myoung Kwon; on behalf of the ROMIAE study group

A case report of furosemide extravasation in the hand: a rare cause of compartment syndrome
Sertaç Güler, Dilber Üçöz Kocaşaban

Colonic high-pressure barotrauma with tension pneumoperitoneum
Sasikumar Mahalingam, Gunaseelan Rajendran, Saravanan Muthusamy, Manu Ayyan, Shirshendu Dhar, Shivani Karn, Mounika Gara, Vignesh Anandharaj

Perinatal carbon monoxide poisoning with fetal and maternal carboxyhemoglobin measurements
Dean T. Odegard, Michael E. Mullins
CPR Dashboard™ featuring Real CPR Help®:
Helps with depth, rate, and release to ensure high-quality CPR.

See-Thru® CPR:
Filters out artifact during compressions so that a clinician can see if an organized underlying rhythm is forming. This can help minimize pause times during CPR and increase chest compression fraction.

OneStep™ Electrodes:
Provide high-current defibrillation and capture CPR quality. Also, monitor, cardiovert, and pace without a separate 3-lead ECG cable.

Automated daily self-checks:
Tests a multitude of items, including battery health and electrode expiration. Sends status of the R Series to Defibrillator Dashboard™ via WiFi.

RescueNet® CaseReview Software:
Collects, collates, and manages code data to simplify debriefing and improve CPR quality.
Use for Paracentesis & Thoracentesis

KARAHOC

dalim medical corp.

4, jandari-ro 3-gil, Mapo-gu, Seoul 04043 Korea
www.dalimmedical.co.kr
Challenges surrounding the emergency physician workforce and their impact on the Emergency Medicine Match

Christopher L. Bennett¹, Michelle Lin¹, Carlos A. Camargo²

¹Department of Emergency Medicine, Stanford University School of Medicine, Stanford, CA, USA
²Department of Emergency Medicine, Massachusetts General Hospital, Harvard Medical School, Boston, MA, USA

INTRODUCTION

Although we believe the future of emergency medicine (EM) remains bright, short-term forecasts are clouded by concerns regarding the 2022 and 2023 Match results and projections of a future surplus of emergency physicians (EPs) [1–4]. On social media, at national conferences, and within our own emergency departments (EDs), our specialty’s trajectory is a common conversation piece with heated opinions. But key questions remain: what got us here and where are we going?

THE (UN)EXPECTED MATCH RESULTS

For many, the 2023 Emergency Medicine Match results came as a surprise. As others have commented, 554 initially unmatched positions in the 2023 Match should have been expected [4]. Amidst a growing controversy over the EP workforce, the Match heightened concerns from many about our specialty’s future [2–5]. However, an important caveat to the Match results are that EM—compared to most other specialties—has one of the fastest 5-year rates of growth in number of new residency programs [6]. Since joining the National Registry Matching Program in 1983, EM has added positions to the Match each year [7]. In 2018, EM offered 2,278 positions and, since then, it has added 732 new positions—a 32% increase! This increase outpaces other specialties (e.g., from 2018 to 2023 internal medicine, surgery, and pediatrics had a 29%, 27%, and 8% proportional growth, respectively) [7,8].

Reasons for the accelerating growth in EM residency positions are multifactorial. First, the migration of osteopathic programs to the Accreditation Council for Graduate Medical Education (ACGME) under the Single Accreditation System (SAS) from 2015 to 2020 resulted in the inclusion of osteopathic programs [9]. Second, there has been a rapid increase in the number of newly accredited residency programs [10]. This includes an increasing number of programs at institutions without a major teaching hospital affiliation and programs sponsored by for-profit hospitals [5]. These new programs are disproportionately added to areas with an already existing density of EM programs (Fig. 1) [5,10].

The lack of major teaching hospital affiliation among newly accredited EM residency programs is troubling [5]. Teaching hospital EDs tend to have higher visit volumes and more often provide complex, higher acuity care by nature of their status as referral centers. This offers EM residents...
training in specialized, multidisciplinary care. However, there are a finite number of teaching hospitals with the necessary infrastructure to create the academic environment for an EM residency. Compared to EM programs with a major teaching hospital affiliation, more recently launched EM programs based at hospitals without a major teaching hospital affiliation are less likely to be designated as a trauma, stroke, or burn center [5]. We acknowledge that teaching hospitals are less likely to be located in rural settings; thus, in medically underserved areas, teaching hospital affiliation may not need to be a prerequisite for EM residency accreditation. However, alternate indicators of the breadth and complexity of training opportunities should be met. Unfortunately, annual ED visit volumes at some newly accredited residencies’ primary site—the ED where the program is based and where residents spend most of their time—are consistently below the ACG-ME’s minimum threshold for annual visit volumes [5]. These low volumes raise concerns about the quality of the educational environment for EM residents in these programs. Moreover, these data suggest that some of these programs do not meet ACGME Common Program Requirements [5].

Another key driver of the growth in EM residencies is the growing role of for-profit entities in academic EM [1,2,11]. As an example, the publicly traded hospital operator Hospital Corporation of America (HCA) accounts for a sizable share of all newly accredited EM residency programs in the United States. Beyond EM, HCA sponsors more than 5,300 residents and fellows in more than 300 residencies and fellowships [12]. Of equal concern is the rise of private equity ownership in EM physician groups, which is estimated to affect 25% to 40% of all US EDs [13]. Concerns have been raised regarding staffing models at institutions affiliated with for-profit entities—in particular, that low physician staffing may adversely impact time and resources available for resident education and potentially even adversely impact patient care [14,15]. The role of for-profit entities places health care facilities at higher financial risk, increasing the likelihood of disruptions to EM residency training. The rapid closure of the Summa Health and Hahnemann EM residencies in 2019 are cautionary tales where financial decisions inflicted direct harm on resident education [16]. The recent bankruptcies of two of the largest EM staffing firms—both backed by private equity—in the wake of the 2022 No Surprises Act raise questions about the continued role of for-profit entities in EP workforce and training [17,18].

THE EP WORKFORCE (AND ATTRACTION FROM IT)

Another potential factor in the 2023 Match outcome was a 2021 report projecting an overall surplus of EPs in the United States by 2030 [3]. The “overall” aspect of this surplus is important; a key assumption of this work was uniform rates of attrition (with annual attrition estimated to range from 2%–4%). We believe that a single national projection is overly simplistic and there are mismatches in where EPs are needed and where they desire to live. Although the EP workforce continues to grow overall, there is persistent regional variation in both EP supply and EP demand [19]. Specifically, urban markets are increasingly saturated and projections of surpluses in these markets are likely correct [19,20]. But there are also EP “deserts” in large swaths of the country [20]. Much of rural America has either insufficient or absent access to EP care (Fig. 2) [20,21]. This includes even more limited access to EPs with EM residency training and EM board certification [21,22]. Recent work demonstrates that this desert continues to grow as
the proportion of EPs working in rural areas decrease [20]. Therefore, rural EP shortages are likely to worsen in the coming years. This widening rural–urban gap is largely driven by an older population of rural EPs who are nearing the retirement age and leaving the clinically active workforce [20–22]. It is exacerbated by evidence demonstrating that residency graduates are likely to continue practicing in urban and suburban environments similar to their training programs [10,23]. Since most new residency programs are not in underserved rural areas, the vision of every person seeking emergency care being seen by an EM-trained (and EM board-certified) EP seems less and less feasible [24]. Regardless of the drivers, the end result is the same—an increased reliance on nonphysician providers and non-EM board-certified physicians [25,26].

Another equally important assumption is that the 2021 estimate of 2% to 4% annual attrition among EPs is based on data from 2013–2019 [3]. More recent evidence suggests the annual rate of EP attrition is at least 5% [27]. Alarmingly, attrition during early stages of the COVID–19 pandemic was more than 8% overall—and even higher for EPs without EM board certification (11%) and those in rural locations (11%) [27]. Given the ongoing stresses of COVID–19, burnout, crowding, boarding, the rise of hallway medicine, and attrition rates are likely to remain higher than prior estimates.

THE 5 (AND 10) YEAR HORIZON

The current trajectory suggests that an increased number of EPs will enter into the clinically active workforce and, with more EM residency programs added each year, the total number of EPs entering the workforce will grow each year [10,20]. Although some residency programs may close, the rate of new program growth will likely result in an overall net gain in EM residency programs [5,10]. This growth will be primarily in urban markets—and reflexively EPs will do what they do best and accommodate. Those who desire to work in competitive markets will find novel ways to provide emergency care (e.g., telehealth) and for some, expand what we now consider our scope of practice. Meanwhile, many rural Americans will continue to receive emergency care by persons without either EM residency training or EM board certification, or nonphysician providers.

We believe the 2023 Match results are a natural extension of workforce and market factors. While it is possible that the unfilled slots will eventually lead to a “reset” and closure of EM residency programs with persistently unmatched positions, the coming years may be a painful transition. To mitigate future adverse impacts, policy solutions and action are needed. Simply waiting for programs with persistently high rates of unmatched positions to close will not resolve the underlying issues that led to the current situation. We recommend critically examining and strengthening ACGME accreditation requirements, which are currently
The emergency physician workforce undergoing revision. We also believe more research is needed to evaluate the impact of for-profit entities on EM training and that all national EM organizations should jointly advocate for greater transparency in this regard. Finally, it is important to create and promote incentives for board-certified EPs to practice in rural and underserved areas, including Public Service Loan Forgiveness programs [20]. The specialty of EM is at a critical inflection point. While we have no doubt it will survive, now is the time to advocate together for changes that secure a bright future for our specialty.

ETHICS STATEMENT

Not applicable.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

FUNDING

None.

AUTHOR CONTRIBUTIONS

Conceptualization: all authors; Writing–original draft: all authors; Writing–review & editing: all authors. All authors read and approved the final manuscript.

ORCID

Christopher L. Bennett https://orcid.org/0000-0002-8467-6192
Michelle Lin Not available
Carlos A. Camargo Not available

REFERENCES

4. Schmitz GR, Jarou ZJ. The Emergency Medicine Match: is the sky falling or is this just growing pains? Ann Emerg Med 2023; 82:608–10.
9. Accreditation Council for Graduate Medical Education (ACGME), Transition to a single GME accreditation system [Internet]. ACGME; c2023 [cited 2023 Aug 28]. Available from: https://www.acgme.org/about/transition-to-a-single-gme-accredita
tion-system-history/
uity-selling-medical-residencies-for-profit.html
Artificial intelligence (AI) and machine learning (ML) have potential to revolutionize emergency medical care by enhancing triage systems, improving diagnostic accuracy, refining prognostication, and optimizing various aspects of clinical care. However, as clinicians often lack AI expertise, they might perceive AI as a “black box,” leading to trust issues. To address this, “explainable AI,” which teaches AI functionalities to end-users, is important. This review presents the definitions, importance, and role of explainable AI, as well as potential challenges in emergency medicine. First, we introduce the terms explainability, interpretability, and transparency of AI models. These terms sound similar but have different roles in discussion of AI. Second, we indicate that explainable AI is required in clinical settings for reasons of justification, control, improvement, and discovery and provide examples. Third, we describe three major categories of explainability: pre-modeling explainability, interpretable models, and post-modeling explainability and present examples (especially for post-modeling explainability), such as visualization, simplification, text justification, and feature relevance. Last, we show the challenges of implementing AI and ML models in clinical settings and highlight the importance of collaboration between clinicians, developers, and researchers. This paper summarizes the concept of “explainable AI” for emergency medicine clinicians. This review may help clinicians understand explainable AI in emergency contexts.

Keywords Artificial intelligence; Machine learning; Resuscitation; Emergency medicine
ARTICLE IN PRESS

Yohei Okada, et al.

INTRODUCTION

Artificial intelligence (AI) and machine learning (ML) are powerful technologies that have the potential to improve medical care [1]. AI refers to the broader concept of technology being able to carry out tasks in an autonomous and smart way, encompassing a variety of technologies, while ML is a subset of AI focused on the idea that machines can learn from data, identify patterns, and make decisions with minimal human intervention [1–4]. Particularly in emergency medicine, AI and ML are expected to play critical roles in accelerating triage, diagnosis, and prognostication to optimize individual patient care through the input of clinical information and/or image recognition [2,4–8]. Furthermore, streamlined clinical documentation or recording using natural language processing is expected to make these tasks more efficient [9–11]. These technologies will also contribute to drug discovery, patient monitoring, resource allocation, and epidemiological surveillance [12–15].

Despite expectations that emergency physicians will become general users of AI and ML in the near future, critics are doubtful whether they can trust and rely on AI and ML models [16]. Physicians are usually not experts in AI and may not have an in-depth understanding of it or ML. When an AI model outputs a medical classification or prediction, without necessarily "explaining" the underlying process or showing the variables and weights driving the prediction, physicians who are not familiar with AI algorithms may perceive an AI model as a “black box.” Such a situation may lead to doubt and mistrust in AI output, a major challenges for implementation of AI and ML tools in clinical settings [17].

To address these concerns, the concept of “explainable AI” has been highlighted as a possible solution for successful implementation of AI and ML in medical practice [18–20]. Explainable AI aims to teach the functioning of AI systems to end-users, researchers, or developers [18–20]. As more accurate, complex models are developed, it may become increasingly difficult to understand how they work. This review introduces the definitions, importance, and role of explainable AI and covers potential related challenges in emergency medicine.

WHAT IS TRANSPARENCY, INTERPRETABILITY, AND EXPLAINABILITY IN AI?

Before discussing the concept of “explainability,” we introduce the terms “interpretability” and “transparency” [18–20]. While these terms have distinct meanings, they are sometimes mistaken for explainability. AI models are often labeled as a “black box,” suggesting a lack of transparency, as shown in Fig. 1A [21]. In an opaque model, the conversion of an input to an output is invisible, making it challenging for users to understand the process. In contrast, transparent/interpretable models allow users to understand how inputs are processed to produce outputs to observe operation of a model, as shown in Fig. 1B. As shown in Fig. 2, straightforward models like linear regression with a limited number of variables or a decision tree with a few branches are easier to understand [21].

Explainability is different conceptually. Arrieta et al. [19] suggested that, “Given a certain audience, explainability refers to the ability of a model to show details and make its internal functioning clear or easy to understand.” This definition emphasizes the audience’s perspective, which can vary by background, experiences, and capacities, resulting in different needs of explainability in ML. While explainability is inherent in transparent models, it is also tied to post hoc explainability, as shown in Fig. 1C. This concept refers to techniques that provide a rationale or explanation

Fig. 1. Black box, transparency, and post hoc explainability. (A) Black-box model. (B) Transparent model. (C) Post hoc explainability. VF, ventricular fibrillation; CPR, cardiopulmonary resuscitation.

Fig. 2. Decision tree model to predict the possibility of survival. You can trace the algorithm to generate the output without any computers or devices. VF, ventricular fibrillation.
to support user understanding of model operation even if the model itself is noninterpretable (often referred to as a “black box”); this may be achieved by providing text or a visual explanation, etc. [22].

WHY IS EXPLAINABLE AI NEEDED IN EMERGENCY MEDICINE?

There are four main reasons why explainable Al is required in clinical settings: justification, control, improvement, and discovery of novel ideas [23]. These four reasons may appear to overlap, but from a clinical perspective, they capture different motivations.

First, explainable AI is useful to justify AI model outputs, to enhance trust, and to support clinical decision-making [23]. Generally, clinicians need to explain a medical condition, treatment plan, and expected outcomes to patients and their families. Despite medical complexity, clinicians need to make the effort to communicate to the patients and their families to facilitate shared decision-making and trust [24]. Thus, explainability is important in a medical decision-making process, and the results generated from clinical Al or ML need to be handled appropriately to build trust. In the absence of a clear and satisfactory explanation, clinicians will likely be hesitant to trust AI. For example, a recent randomized control trial investigated the efficacy of an AI model that aims to detect cardiac arrest cases at the dispatch center using voice data analysis during an emergency call [25,26]. The study was unable to demonstrate the effectiveness of the AI model, with the researchers suggesting that some dispatchers might not have trusted the output from the AI model due to the absence of a reasonable explanation. Explainable AI can produce an auditable and testable way to defend algorithmic decisions as fair and ethical [27,28].

Second, explainability helps users maintain control of a complex technology. Indeed, a deeper understanding of AI models increases awareness of vulnerabilities and flaws [23], which can help to quickly identify and correct (debug) errors in critical situations. Thus, user controls can be strengthened. If the AI generates unexpected results and unreasonable explanations inconsistent with clinical experience or show potential risk of bias/discrimination, clinicians can bypass the AI and review results for errors or bias [29]. For example, if a patient is unexpectedly evaluated as having low likelihood of a favorable outcome, mainly driven by ethnicity or socioeconomic status of the patient, clinicians may suspect hidden discrimination or bias in the AI training data [30,31].

Third, explainability of AI models is needed to allow continual improvement. If AI models can discuss the process used to produce specific results, the information can be used for further improvements [32]. For example, when an AI model does not accurately predict an outcome, its process can be determined using explainability features. If a certain predictor highly contributes to a model but carries a risk of measurement bias due to the absence of standardized definitions in clinical settings, the model might be improved by excluding the variable or standardizing the input. In this way, explainable AI can lay the groundwork for continuous iteration and improvement.

Furthermore, explainable AI may allow development of new ideas, hypotheses, and knowledge [22]. For example, if an explanation from an AI model shows an unexpected contribution of a certain risk factor to the prediction of outcomes, a novel hypothesis might be developed regarding this factor and its association with outcomes. In an AI study investigating clinical subgroups of cardiac arrest patients treated effectively with extracorporeal cardiopulmonary resuscitation (ECPR), creatinine value was associated with outcome. This led to the development of a novel score for indications of ECPR that included creatinine [33]. The importance of explainable AI is increasing with the more critical role of AI in clinical settings.

HOW DOES EXPLAINABLE AI WORK?

Explainable AI encompasses three main approaches [18–20]. The first is pre-modeling explainability, such as data visualization, summarization, and transformation [34]. Before deploying Al in clinical settings, it is essential to grasp the data structure, patients’ characteristics, time trends, and proportion of the outcome for an appropriate understanding of the AI. This may include simple descriptions, such as mean, standard deviation, and range, and missing data using data visualization or summarization. Data transformation is also crucial to change row data into a usable format or structure [34]. For example, when developing ML models, clinical data such as the date of incidence, time of emergency call, and hospital arrival are generally transformed to the month or day of an incident or the duration between the emergency call and the time of hospital arrival, allowing easier analysis. Data transformation is more applicable to development and understanding of models.

The second approach is to develop an interpretable model with inherent understandability or a blend of different model types [18–20]. Models exhibit various levels of interpretability and transparency: at the level of the training algorithm (referred to as “algorithmic transparency”), at the component level (known as “decomposability”), and at the level of the model itself (or “simulatability”) [22]. For example, as shown in Fig. 2, a tree model might pose a human-understandable question, such as whether the patient is younger than 65 years to clarify the prediction process.
and enhance algorithmic transparency. Such a model can be broken down into individual segments, like patients with or without initial ventricular fibrillation (VF) (Fig. 2). This allows users to identify the contribution of each segment to the overall output, showcasing decomposability. In an example of a 40-year-old cardiac arrest patient with initial VF, we can follow the entire prediction pathway of the model, estimating a survival probability of 30%, without specialized mathematical tools. This demonstrates simulatability, with model transparency and user-friendly interpretation.

A hybrid interpretable model approach has also been proposed [18–20]. It includes a set of methods that attempt to combine a complex black-box model with an inherently interpretable model to build an interpretable model that achieves comparable performance to the black-box model. The AutoScore framework is an example of this hybrid interpretable model approach [35,36]. In this framework, development of an ML model is complicated, but the final result is familiar to users [5,35,37].

The last method is called post-modeling explainability [18]. It helps break down complex developed AI models so that they are easier to understand. These techniques were created based on human understanding.

**POST-MODELING EXPLAINABILITY**

In this section, we introduce some examples of post-modeling explainability. Fig. 3 shows several categories of post-modeling explainability, including visualization, textual justification, simplification, and feature relevance [22].

Text explanations improve the understanding of ML models by generating text-based explanations in the form of phrases or sentences using natural language generation methods. Examples include AI models used to classify pathological images, which attempt to provide user-friendly explanations [38]. These models can generate sentences such as: “The input image is diagnosed as tissue A type for sure because it could not be misclassified to any other tissue types”; “The input image is suspected as tissue B type, and there is a low possibility that it could be tissue C type, D type, or E type”; or “The input image is tissue A type. However, there is a possibility that it could be tissue F type.” These explanations about the possibilities of misclassification provide rationale for predictions and help clinicians with their decision-making (Fig. 3).

Visual explanations describe models by applying techniques that aim to visualize the model behavior. Popular literature makes use of dimensionality reduction techniques to produce simple visualizations that can be easily interpreted by humans. Visual explanation is particularly effective in conveying complex interactions between variables [18–20]. For instance, when describing black-box models to predict the probability of favorable outcomes for cardiac arrest patients, the interactions between probability and some factors (such as age and transport time to the hospital) are difficult to recognize. In explainable AI, these variables can be visualized to provide insights into the interactions (Fig. 4).

**Fig. 4.** Visualization of interactions between factors and outputs. This plot illustrates the relationships between the factors (age and time to hospital) and the predictions of the random forest machine-learning model. This random forest model was constructed to predict the survival probability using simulated data from cardiac arrest patients, including patient age and gender, whether the event was witnessed, provision of bystander cardiopulmonary resuscitation, and the time from the call to arrival at a hospital. The x-axis represents age, while the y-axis denotes the time from the call to arrival at a hospital. Blue dots indicate cases with a low probability of survival (<25%), red dots are cases with a high likelihood of survival (>35%), and white dots signify intermediate cases (around 30%). While users might not grasp the intricacies of artificial intelligence model prediction, they can broadly infer that patients who are younger and have a shorter time to reach a hospital are predicted to have higher survival rates. Conversely, older patients with a longer time to reach a hospital are estimated to have lower survival probability. Moreover, users can observe the interactions between factors and predictions.
plotted along the x-axis and y-axis, respectively, to create a scatter plot (Fig. 4) of the distribution of the possibilities [39]. This approach visualizes the predicted probability of interaction between the factors.

Simplification creates a straightforward, less complicated interpretable model from a black-box model [22]. One example of simplification is selection of a single decision tree as the representative of a random forest ensemble of numerous decision tree models [40,41]. A simplified model could aggregate predictions from the individual trees to produce a final output, as shown in Fig. 3 [42]. Although this approach is commonly utilized in medical research, the results can be challenging to interpret due to the ensemble nature. Identifying a single tree that captures the primary patterns and behaviors of the entire forest allows a bal-

Fig. 5. Example of Shapley Additive Explanations (SHAP) values. (A) The waterfall plot indicates the predicted value (i.e., f(X)) of each factor for a 45-year-old female who suffered cardiac arrest with witnesses and time to the hospital of 37 minutes. The change in predicted value from baseline (−1.495, corresponding to a survival rate of 18.3%) to that for this particular case (−1.293, corresponding to a survival rate of 21.5%) attributed to each factor is the SHAP value of each factor. The survival probability is calculated as the inverse logit function given by \( \frac{1}{1+e^{-f(X)}} \). (B) The beeswarm plot demonstrates the SHAP values of each factor across all cases. A central vertical line (at SHAP value=0) indicates “no influence” on the prediction. If a point is to the right of this line, it means that the factor influences the model predictions in a positive direction (increases the survival rate); if it is to the left, it influences predictions in a negative direction (decreases the survival rate). The color of the dot represents the value of the factor. For example, red and blue correspond to female or male for sex and “witnessed” and “not witnessed” for witness status. Also, red or blue means older or younger in age. (C) The bar plot displays the absolute SHAP values, indicating that factors of time to hospital, witnessed status, and age are more relevant predictors of survival than age across all cases.
ance between interpretability and performance [40,41]. This representative tree can be visualized, providing insights into the decision-making process using the same foundational logic as the original ensemble. Another example is the local interpretable model-agnostic explanations (LIME) approach [43], which approximates a complex black-box model with a simpler and more easily interpretable linear regression model. This is achieved by generating numerous samples of input data, predicting their outputs using the original model, and then training a linear model on these samples with emphasis on those close to the original data point. LIME can identify the feature importance that contributes most to each prediction and helps users determine the factors most crucial in the, as explained below.

Explanation by feature relevance aims to provide post-modeling explainability by assessing the internal processes of an algorithm. This type of explanation is commonly utilized in ML models in emergency medicine [33,44–47]. It calculates relevance scores for all variables managed by the algorithm to quantify the importance of features critical to model decisions. Shapley Additive Explanations (SHAP) is one of the methods used to evaluate the contribution of each input feature to AI model operation [48,49]. Similar to LIME, SHAP performs local linear approximations to explain the predicted risk for each individual. However, it uses a different approach that allows more desirable properties than LIME in terms of local accuracy and consistency (for details, please see the reference) [49].

SHAP can quantify and visualize how each factor increases or decreases risk from baseline to reach the predicted risk for each individual using a waterfall plot, as shown in Fig. 5. Consider an ML model that predicts the survival rate of cardiac arrest patients using sex, age, witness status (yes/no), and time to the hospital from the emergency call (minutes). For example, consider a 45-year-old female with witnessed arrest and a time to hospital of 37 minutes. This ML model predicts her survival rate as 21.5%. The waterfall plot in Fig. 5A demonstrates how these four factors influence the prediction of ML. In this case, the baseline of the predicted value (f(X)), i.e., the average prediction across all cases, is –1.495, which translates to a baseline survival rate of 18.3% via the inverse logit function \(1/(1+e^{-0.00})\). The witnessed status increases the predicted value by 0.103, which is equivalent to an increase in the survival probability to 19.9% from baseline. This 0.103 increase in the predicted value attributable to the witnessed status is the SHAP value of this factor for this individual. The patient’s sex (female) has a SHAP value of 0.147, which further increases the survival probability to 22.4%. Additionally, the patient’s age (45 years old) has a SHAP value of 0.22, which increases it further to 26.4%. However, the time taken to reach a hospital, which has a negative SHAP value of –0.268, reduces the survival rate to the final predicted value of 21.5% for this particular case. Through this example, we can understand how each variable impacts the model prediction using a waterfall plot and SHAP values. This demonstrates how SHAP can provide local explanations for individual predictions. When the contributions to the predicted risk of each factor are visualized across all patients in a beeswarm plot (Fig. 5B), the relationships between factor levels and contributions to prediction can be determined, facilitating a straightforward comparison of the impact of each factor on the prediction.

SHAP is also valuable for global explanations to understand how the model behaves overall. This is done by considering all data points using the average absolute SHAP value. For example, the bar plot in Fig. 5C indicates that the average absolute SHAP value of “time to hospital” is highest, while those of “witnessed” and “age” are lower but still considerably high compared to that of “sex.” The model suggests time to hospital, witnessed status, and age as strong predictors of survival. This dual capability allows users to understand both specific decisions of the model and the broader trends and behaviors across data points.

**CHALLENGES IN IMPLEMENTATION INTO CLINICAL SETTINGS**

Even though the explainability of AI has advanced, there remain several challenges to the implementation of AI models in clinical settings. One of the issues is whether the explanation is acceptable and trustworthy enough from the points of view of clinicians and patients [16,18–20]. Previously, an explainable AI model was developed to predict the deterioration of patients with subarachnoid hemorrhage in the intensive care unit. To enhance the implementation of the AI tool, the perception gap between the developers and clinicians was investigated [50]. Through interviews, the study found that the developers believed that clinicians must be able to understand model operation and developed the AI model with explainability by providing SHAP values, as mentioned above. In contrast, from the perspectives of the clinicians, the SHAP value was not sufficiently helpful in understanding or trusting the AI model. Clinicians were more focused on clinical plausibility based on the pathophysiological rationale or clinical experience and a holistic approach referring to the multispectral clinical information. As illustrated in this example, the kind of explainability required depends on the audience and context of use of the AI model [19]. In emergency settings, the contexts and patient conditions change rapidly. Especially during resuscitation, which is an incredibly time-critical situation, clinicians may not have adequate
time to try to understand how AI models work. Therefore, a model must be understandable quickly. Furthermore, it is a challenge to assess the quality/effectiveness of explainability. A previous systematic review reported various methods for assessing explainable AI effectiveness, with few established methods [51]. Establishing standardized approaches to measure the effectiveness of explainable AI might increase its integration into clinical settings and act as a tool of communication among clinicians, researchers, and developers [28]. Finally, with increasing emphasis on fair and trustworthy AI-assisted decision-making in clinical settings, the contribution of explainable AI to model development should be determined through a multidisciplinary approach [52]. Considering such situations, collaboration among AI developers, researchers, and clinicians in designing explainable AI systems is imperative for improving their effectiveness, usability, and reliability in healthcare.

CONCLUSION

This paper summarizes the concept of "explainable AI" for clinicians in emergency medicine. With the expected increasing role of AI in medicine, emergency physicians and researchers will need to become knowledgeable about its use. Furthermore, a multidisciplinary approach is essential to develop trustworthy AI for use in clinical emergency medicine. This review will help interpret explainable AI to clinicians working in emergency departments.

ETHICS STATEMENT

Not applicable.

CONFLICT OF INTEREST

Yohei Okada has received a research grant from the Zoll Foundation and overseas scholarships from the Japan Society for Promotion of Science, the Fukuda Foundation for Medical Technology, and the International Medical Research Foundation. Marcus Eng Hock Ong reports grants from the Laerdal Foundation, Laerdal Medical, and the Ramsey Social Justice Foundation for funding of the Pan-Asian Resuscitation Outcomes Study and an advisory relationship with Global Healthcare SG, a commercial entity that manufactures cooling devices. Funding from Laerdal Medical was received for an observation project of the Community CPR Training Centre Research Program in Norway. Marcus Eng Hock Ong is a Scientific Advisor to TIIM Healthcare SG and Global Healthcare SG. Marcus Eng Hock Ong is also an Editorial Board member of Clinical and Experimental Emergency Medicine, but was not involved in the peer reviewer selection, evaluation, or decision process of this article. No other potential conflict of interest relevant to this article was reported.

FUNDING

This study was supported by a scientific research grant from the Japan Society for the Promotion of Science (JSPS) KAKENHI (No. JP22K21143/23K16253) and by the Zoll Foundation.

ACKNOWLEDGMENTS

The authors thank Professor Liu Nan (Health Services and Systems Research, Duke-NUS Medical School, Singapore) for his support and helpful advice.

AUTHOR CONTRIBUTIONS

Conceptualization: YO, MEHO; Funding acquisition: YO, MEHO; Methodology: YN; Writing–original draft: YO; Writing–review & editing: YN, MEHO. All authors read and approved the final manuscript.

ORCID

Yohei Okada https://orcid.org/0000-0002-2266-476X
Yilin Ning https://orcid.org/0000-0002-6758-4472
Marcus Eng Hock Ong https://orcid.org/0000-0001-7874-7612

REFERENCES


to develop interpretable scoring systems for predicting common types of clinical outcomes. STAR Protoc 2023;4:102302.


Point-of-care ultrasound (POCUS) is a rapidly developing technology that has the potential to revolutionize emergency and critical care medicine. The use of POCUS can improve patient care by providing real-time clinical information. However, appropriate usage and proper training are crucial to ensure patient safety and reliability. This article discusses the various applications of POCUS in emergency and critical care medicine, the importance of training and education, and the future of POCUS in medicine.

Keywords Point-of-care systems; Ultrasonography; Emergencies; Critical care; Pediatrics
INTRODUCTION

Point-of-care ultrasound (POCUS) is an ultrasound examination performed and interpreted by the clinician at the bedside to obtain specific clinical information. Although first used by clinicians in the 1960s, POCUS had not become increasingly popular in the 1990s, which subsequently resulted in it being labeled the “visual stethoscope” of the 21st century [1,2].

POCUS exam had been designed to address a specific clinical inquiry with a focused, goal-directed evaluation. Its objective is to either “rule in” or “rule out” specific conditions or answer a “yes or no” question [3–5]. By contrast, a comprehensive ultrasound (standard consultative ultrasound) performed by radiologists or cardiologists thoroughly evaluates the entire anatomical region. Ordering, executing, interpreting, and reporting such comprehensive ultrasound examinations typically take hours or days, whereas POCUS examinations provide clinical information in real-time within minutes. Recent studies have shown that POCUS can increase diagnostic accuracy and significantly reduce physicians’ diagnostic uncertainty [6]. Moreover, most patients admitted to an emergency department who agreed to undergo POCUS of the heart, lungs, and deep veins reported “very low” discomfort [7].

Clinicians have also released statements advocating for POCUS [8,9]. Additionally, undergraduate medical students who have encountered POCUS examinations earlier in their medical education have gained a better understanding of the clinical applications of POCUS [10]. POCUS has become increasingly popular in emergency medicine (EM), and so has POCUS education in residency programs [11].

With the increased use of ultrasound in emergency and critical care settings, countries with emergency rooms and intensive care units (ICU) equipped with an ultrasound system have recently implemented health insurance coverage for POCUS in emergency and critical care areas. Ultrasound practice is facilitated by standardized scopes and indications of use recommended by each country [12]. Although POCUS has been a rapidly growing technology in emergency, trauma, and critical care medicine, some concerns have been raised regarding its patient safety, which include overuse, inaccurate diagnoses, inappropriate usage, and excessive dependence on POCUS [13,14]. To improve patient care and prevent unnecessary cuts in healthcare budgets, proper prescription, application of POCUS, as well as documentation of its findings, are required [15].

This paper aims to comprehensively review the different types of POCUS used in clinical practice for emergency and critical care medicine, so that clinicians performing POCUS can better understand POCUS indications and limitations.

POCUS ULTRASOUND: EQUIPMENT AND INSTRUMENTATION

The miniaturization of ultrasound machines and the increase in computing capacity have facilitated the development of portable ultrasound devices [16–18]. Currently, a vast selection of ultrasound devices is available in the POCUS market [19]. Given the developments in signal computational capacity, even the smallest mobile devices now provide high-quality images. Moreover, the price of POCUS has decreased dramatically, making the technique more accessible to physicians.

Several types of ultrasound machines have been used for POCUS, which can be categorized as “compact cart-based,” “hand-carried,” and “handheld or pocket-sized” (Fig. 1). Compact cart-based devices are designed to be brought to the patient’s bedside. They possess the most advanced features with powerful processors and have the largest screen size and memory. However, these devices have some disadvantages including their large size, less maneuverability, indoor use only, short battery time, and high
Fig. 1. Three types of ultrasound devices for point-of-care ultrasound. (A) Compact cart-based. (B) Hand-carried. (C) Handheld or pocket-sized.

Fig. 2. Portable ultrasound by connecting a probe wirelessly with mobile phone applications.

Focused cardiac ultrasound (FoCUS) is used to rapidly assess cardiac anatomy and function in critically ill patients at the bedside. The five basic views recommended for FoCUS examination include the parasternal long axis, parasternal short axis, apical four chamber, subcostal four chamber, and subcostal inferior vena cava (IVC) views [20,21]. grayscale ultrasound is used to evaluate cardiac structure, during which depth and gain adjustments should be set for optimal visualization. Color Doppler analysis of the mitral and aortic valves to identify regurgitation may be included in the examination [6,22]. Assessments with FoCUS can identify several causes in time-sensitive clinical scenarios related to cardiorespiratory symptoms and signs (Table 1) [15,21,23,24].

Limitations and special considerations of FoCUS

The limitations of FoCUS related to patients include body habitus, surgical dressing or chest drains, and subcutaneous emphysema, which may increase the difficulty of obtaining clear images during a FoCUS examination. False-positive or false-negative results may occur due to off-axis viewing when scanning is not performed in the appropriate position for optimal image acquisition. Additionally, FoCUS has limitations in verifying some cardiac conditions such as pericardial fat pads, cysts, preexisting or small pericardial fluid, diastolic dysfunction, valvular diseases, and pulmonary hypertension [25]. Comprehensive echocardiography or
additional diagonal modalities should be considered for a complete evaluation of uncertain findings or complex clinical presentations.

To perform FoCUS accurately and effectively, proper education and training are required. FoCUS training typically includes a combination of didactic instruction, hands-on training, and supervised clinical experience [26]. Trained physicians should be able to demonstrate proficiency in obtaining and interpreting FoCUS images before performing the examination independently. Continuous quality improvement and education are important to maintain and improve the accuracy and reliability of FoCUS.

Table 1. Clinical scenarios that require focused cardiac ultrasound and what can be identified through assessment

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Assessment</th>
<th>Identification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acute chest pain</td>
<td>Aortic root diameter</td>
<td>Active hemorrhage</td>
</tr>
<tr>
<td>Cardiac arrest</td>
<td>Intracardiac mass or thrombus</td>
<td>Acute myocardial infarction</td>
</tr>
<tr>
<td>Cardiac trauma</td>
<td>IVC size and collapsibility</td>
<td>Aortic dissection or aneurysm rupture</td>
</tr>
<tr>
<td>Dyspnea</td>
<td>LV dimension and contractility</td>
<td>Cardiac contusion</td>
</tr>
<tr>
<td>Undifferentiated shock</td>
<td>LV regional wall motion abnormality</td>
<td>Cardiac tamponade</td>
</tr>
<tr>
<td></td>
<td>Pericardial fluid</td>
<td>Gross chronic heart disease</td>
</tr>
<tr>
<td></td>
<td>RV size and strain</td>
<td>and valvular abnormality</td>
</tr>
<tr>
<td></td>
<td>Valve morphology and regurgitation lesion</td>
<td>Pulmonary embolism</td>
</tr>
</tbody>
</table>

IVC, inferior vena cava; LV, left ventricle; RV, right ventricle.

THORACIC ULTRASOUND

Thoracic ultrasound has been increasingly used in the management of patients who visit the emergency department due to acute dyspnea and respiratory failure. This is due to its effectiveness in aiding decision-making for differential diagnosis and treatment. Unlike simple radiography and computed tomography (CT), thoracic ultrasound can be quickly and safely applied to patients, making it an effective choice for early imaging examinations [27,28].

Clinical application of thoracic ultrasound

Since Lichtenstein and Meziere [29] announced the BLUE (Bedside Lung Ultrasound in Emergency) protocol in 2008, experts [21,30] have suggested the use of lung ultrasound for pneumothorax, alveolar-interstitial syndrome, pulmonary consolidation, pleural effusion, and neonates and pediatrics, with robust evidence and strong recommendations in 2012.

Normal lung pattern

When a normal lung pattern, characterized by a bat sign, A line, and lung sliding are observed on lung ultrasound, pneumothorax and interstitial syndrome can be excluded (Fig. 3A). However, when a normal lung pattern is observed in patients who complain of acute dyspnea or breathing difficulties, airway diseases such as asthma or chronic obstructive pulmonary disease, may be consid-

Fig. 3. Various lung artifacts. (A) The A-line artifacts are created by reverberation of ultrasound waves at the pleural line. (B) The B-line artifacts are hyperechoic vertical artifacts which extend from the pleural line to the bottom of the image. (C) If consolidation touches the pleural line, ultrasound penetrates it directly, resulting in visualization without artifacts. Each arrow points to the corresponding artifact finding.
Pneumothorax
The absence of lung sliding may indicate pneumothorax, which may be confirmed through lung point observation (sensitivity, 91%; specificity, 98%) (Fig. 4) [30]. However, care should be exercised for tension pneumothorax, including the whole pleural cavity, given that a lung point cannot be observed in such cases. Checking the lung pulse and B-lines can ultimately exclude pneumothorax.

Interstitial syndrome
Interstitial syndrome can be diagnosed through the presence of more than three B lines in the intercostal space (sensitivity, 94%; specificity, 92%) [31]. Although pulmonary edema due to heart failure is the most common clinical cause of interstitial syndrome, various other heart and lung diseases have been shown to cause the same condition (Fig. 3B).

Consolidation
The most common clinical cause of consolidation is pneumonia. Given the various locations and forms of pneumonia, various presentations can also be observed on thoracic ultrasound (Fig. 3C). Subpleural consolidation and tissue-like patterns are typical and can be diagnosed even if a shred sign or effusion is visible on the posterior examination (sensitivity, 94%; specificity, 96%) [32].

Effusion
Pleural effusion can be easily diagnosed on thoracic ultrasound, which is superior to radiography and CT in measuring the quantity and predicting the properties of effusion. Real-time ultrasound guidance can also help physicians safely perform procedures, such as thoracentesis.

The BLUE protocol
The BLUE protocol is a fast and accurate bedside lung ultrasound technique for diagnosing acute respiratory failure. It involves scanning three points on each hemithorax and identifying specific ultrasound signatures. The BLUE protocol is part of a larger framework for critical care ultrasound [33].

ABDOMINAL POCUS
Abdominal POCUS can be performed in any patient with abdominal symptoms complaining of abdominal pain, flank pain, and a distended abdomen. The advantages of POCUS include rapid performance, avoidance of unnecessary radiation and contrast exposure, quick diagnosis, and potential reduction in length of hospitalization and costs [34–38].

Clinical applications of abdominal ultrasound
Right upper quadrant of the abdomen
POCUS for right upper quadrant (RUQ) pain is a useful tool for evaluating acute cholecystitis. The most significant positive findings are the sonographic Murphy sign, the presence of cholelithiasis, gallbladder wall thickening, and pericholecystic fluid collection. Dilatation of the common bile duct can also be identified in the RUQ areas. Recent studies have suggested that POCUS performed by EM physicians and radiologists had similar accuracy in detecting acute cholecystitis [39,40].

Renal and aortic ultrasound
Renal POCUS aids EM physicians in detecting hydronephrosis in renal colic patients. Additionally, bladder ultrasound helps detect ureterovesical junction or bladder stones, and the absence of ure-
teral jet in patients suspected to have obstructive uropathy [41, 42]. POCUS of the aorta includes measuring the diameter of the abdominal aorta and inspecting for the presence of an intimal flap in the case of aortic dissection using both the transverse and longitudinal ultrasound planes. Moreover, aortic ultrasound can help emergency physicians identify a ruptured abdominal aortic aneurysm (AAA) with high sensitivity and specificity [43,44].

Various gastrointestinal diseases
POCUS is a valuable tool for diagnosing various gastrointestinal pathology. POCUS findings for small bowel obstruction include increased loop dimensions, increased or decreased peristaltic movements (to-and-fro sign), and enlarged and visible valvulae conniventes (keyboard sign) [45,46]. In patients with right lower quadrant abdominal pain, a noncompressible tubular structure with a target sign greater than 6 mm in diameter at the site of the appendix is suggestive of acute appendicitis [47]. In women of reproductive age, pelvic pain or lower abdominal pain can be caused by ovarian torsion or ovarian cyst rupture. Due to the difficulty in diagnosing ovarian torsion or ovarian cyst rupture based on symptoms and physical examination alone, POCUS has become the primary modality for its evaluation [48].

ULTRASOUND-GUIDED PROCEDURES
Ultrasound guidelines, including those from the American College of Emergency Physicians (ACEP) and other organizations, should incorporate guidance on procedures considering the integral role these procedures play in patient management, as well as in enhancing the safety and efficacy of interventions [49]. This improves ultrasound technology has widened the scope of guidelines beyond disease diagnosis and management to include procedural guidance to ensure optimal patient care in every setting.

In critically ill patients, bedside needle procedures such as central venous catheter insertion, thoracentesis, and pericardiocentesis are frequently required. Ultrasound-guided procedures have significant advantages over landmark-based approaches [50–54]. The increasing availability of ultrasound machines, and portable devices, as well as the continued emphasis on patient safety in critical care, have contributed to the growing utilization of ultrasound-guided procedures.

Ultrasound-guided techniques can be classified into two categories: static and dynamic. The static technique involves using ultrasound to locate a target structure and fix the medical instrument, whereas the dynamic technique enables continuous visualization of the needle or instrument as it progresses toward the target. Both approaches have advantages and disadvantages.

Ultrasound probes can be positioned in three axes: short (perpendicular to the structure’s long axis), long (parallel to the structure’s long axis), and oblique (at an angle to the long axis) [55–57]. Each axis provides a different view for visualization, with the short, long, and oblique axis offering cross-sectional, lengthwise, and angled perspectives, respectively.

After positioning the probe in an axis, two techniques are commonly used: in-plane and out-of-plane. The in-plane technique aligns the needle or instrument with the ultrasound probe, allowing direct visualization of both the instrument and the target structure on the same ultrasound image. Although considered accurate and safe, this technique requires precise needle positioning. The out-of-plane technique positions the needle or instrument in a different plane from the probe, resulting in separate visualization of the needle and target structure [58,59].

The choice of technique could depend on specific situations and practitioner preference. However, practitioners need to be proficient in all techniques to ensure optimal outcomes [60]. Micropuncture needles (21 gauge) have become popular in EM and critical care due to their smaller size, reduced bleeding risk, and improved tolerance for multiple vessel wall punctures [61].

TRANSCRANIAL ULTRASOUND
Patients with altered consciousness should undergo CT or magnetic resonance imaging to rule out intracranial lesions. However, these imaging modalities are not always available, and transporting patients with unstable vital signs for radiologic studies may be challenging. In those situations, immediate and noninvasive bedside tests are imperative.

Transcranial ultrasound (TUS), which was first introduced in 1982 had subsequently become a routine clinical procedure for qualitatively and noninvasive evaluation of intracranial blood flow [62]. The development of B-mode ultrasound has helped clinicians evaluate the brain parenchyma. Despite providing inferior quality images compared to CT, ultrasound is capable of providing sufficient image quality for appropriate clinical management, such as the detection of acute hematomas and midline shifting due to the mass effect in the brain parenchyma [63].

The TUS examination is performed via the temporal approach with a low frequency phased array transducer. The main structures needed to be identified on the screen include the contralateral temporal bone at the bottom of the screen and the butterfly-shaped midbrain in the center of the screen. Lastly, the third ventricle should be identified when the probe is slightly tilted.

In general, two types of brain lesions should be easily noticeable through TUS [64]. The first is acute hematoma, which ap-
pears as an echo-enhancing mass within the brain parenchyma (Fig. 5). The second is a midline displacement in which the third ventricle is displaced in the opposite direction due to the mass effect (Fig. 6). However, given that the skull becomes thicker with age, resulting in the attenuation of ultrasound waves, insufficient image qualities are obtained in approximately 5% to 20% out of patients [65]. Although recent attempts have been made to increase the diagnosis rate using contrast agents, future studies will be necessary to overcome these limitations [66].

**POCUS IN CARDIORESPIRATORY ARREST**

During cardiac arrest, POCUS is primarily utilized to guide procedures, immediately identify and treat reversible causes, monitor the quality of chest compression, and predict outcomes [67,68]. POCUS can be considered as an additional evaluation method in cases when the operator is highly skilled and its use does not impede chest compressions [68,69].

Although quantitative capnography has been considered the gold standard for confirming endotracheal tube placement, its sensitivity decreases in prolonged cardiac arrest [70–72]. Thus, physicians have attempted to use POCUS to confirm endotracheal tube placement, with their findings showing reliable accuracy [73–76]. In particular, real-time confirmation showed higher accuracy.

Central venous access can be considered in cases where intravenous access through subcutaneous veins is difficult or extracorporeal cardiopulmonary resuscitation is required [77]. Conventional central venous access has several disadvantages, including interrupt-
tion of cardiopulmonary resuscitation, technical difficulty, and several complications [78]. Ultrasound-guided central venous access can greatly increase stability, accuracy, and efficiency [79–81]. Ultrasound-guided supraclavicular subclavian access using an endocavity probe improves vein identification, anatomical understanding, and procedural comfort following a brief training session [82].

POCUS can help determine cardiac tamponade, left ventricle failure, pulmonary embolism, hypovolemia, and tension pneumothorax [83,84]. Several protocols have been established to identify the causes of cardiac arrest (FATE [Focused Assessed Transthoracic Echocardiography], FEER [Focused Echocardiographic Evaluation in Resuscitation], CAUSE [Cardiac Arrest Ultra-Sound Exam], SESAMI [Sonography in Shock and Acute Management in Intensive Care], ShoC [Sonography in Hypotension and Cardiac Arrest], etc.) [85–89]. POCUS is best performed in the subxiphoid or apical window to avoid interfering with chest compressions. The BLUE and PLAPS (Posterior and/or Lateral Alveolar and/or Pleural Syndrome) points are used to evaluate the lung, whereas a subcostal window is used to evaluate the inferior vena cava. Finally, proximal leg veins are scanned to confirm deep vein thrombosis, and Focused Assessment with Sonography in Trauma (FAST) is performed to identify sources of blood loss.

Some physicians have attempted to determine the prognosis of cardiac arrest using POCUS. Especially, they found that pulseless electrical activity (PEA) without cardiac activity was associated with a worse prognosis than PEA with cardiac activity. Moreover, the likelihood of return of spontaneous circulation (ROSC) was considerably lower in the absence of cardiac activity on serial POCUS [84,90]. However, nonserial POCUS demonstrated poor performance in predicting ROSC.

To monitor chest compression quality, transesophageal echocardiography (TEE) can be a good option. However, TEE requires performers to be highly trained [67,91]. Recently, attempts have been made to monitor chest compression quality through TTE (subcostal or apical window) [92].

More studies are needed to obtain evidence in support of including POCUS as a part of the resuscitation algorithms [93].

**POCUS IN THE DIAGNOSIS AND MANAGEMENT OF SHOCK**

POCUS can provide real-time physiologic information for patients in shock. This approach can also be useful in identifying the cause of shock, classifying the type of shock, guiding treatment, and evaluating the response to therapy. Multifocal ultrasonography can be used for the initial evaluation of undifferentiated shock to identify the cause and provide prompt treatment [94].

When using ultrasonography in shock, the main goals should be to assess the presumed etiology and category of shock and monitor the real-time response to management to optimize treatment efforts. Practical tips for using ultrasonography include performing basic examinations of the heart, lungs, and IVC to recognize the category of shock, as well as supplementary examinations of free fluid in the abdomen, abdominal aorta, intra-abdominal solid organs, peripheral vessels, and other areas to evaluate the cause of shock (Table 2).

Examinations should be performed using multiorgan views and windows. Accordingly, cardiac examination should assess left and right ventricular size and function, pericardial effusion, gross regional wall motion abnormalities, and gross valvular abnormalities. Thoracic examination should evaluate pleural effusion, B-lines, and lung sliding. Vasculature examination should assess the size and collapsibility of the IVC, aorta, and femoral/popliteal veins.

The key ultrasound findings associated with shock are summarized in Fig. 7. Several protocols have been developed for the evaluation of patients in shock, including the RUSH (Rapid Ultrasound in Shock) protocol [95,96], SHoc (Sonography in Hypotension and Cardiac Arrest) protocol [89], ACES (Abdominal and Cardiac Evaluation with Sonography in Shock) [97], FATE [85], and FEEL (Focused Echocardiography Evaluation in Life Support), among others. These protocols include assessments of cardiac function, volume, and vasculature [83].

The RUSH protocol involves a three-part bedside assessment of the pump (heart), tank (fluid status), and pipes (vasculature), with a stepwise evaluation outlined in Fig. 7 [96]. The ShoC protocol recommends core, supplementary, and additional views as outlined in Fig. 8 [98].

**EXTENDED FAST**

FAST examination is a noninvasive point-of-care test that aims to guide clinical decision-making and direct angiographic or surgical interventions. It can be a powerful tool for clinicians, especially in time-dependent situations such as trauma. Extended FAST (eFAST) is an evolution of the traditional FAST that incorporates thoracic window assessment to identify hemothorax and pneumothorax [98–100]. The physiologic priority of ABCD (airway, breathing, circulation, and disability) in injured patients should be assessed using a multisystem, multifocused, problem-based POCUS as an extension of physical examination [101,102]. This ultrasound-enhanced trauma life support, called FAST-ABCD, can provide a considerable amount of important information that could help the primary physician make critical decisions by systematically combining airway, lung, cardiovascular, abdominopelvic,
Table 2. The key ultrasonography finding for evaluating the category and causes of undifferentiated shock

<table>
<thead>
<tr>
<th>Exam</th>
<th>Hypovolemic</th>
<th>Cardiogenic</th>
<th>Obstructive</th>
<th>Distributive</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cardiac exam</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left ventricle</td>
<td>Hyperdynamic function</td>
<td>Decreased function</td>
<td>Hyperdynamic function</td>
<td>Hyperdynamic or hypocontractile</td>
</tr>
<tr>
<td></td>
<td>Dilated chamber</td>
<td>Valve abnormality?</td>
<td>Pericardial effusion+chamber collapse</td>
<td>or normal function</td>
</tr>
<tr>
<td>Right ventricle</td>
<td>Normal or small size</td>
<td>Dilated chamber?</td>
<td>Dilated, strained RV</td>
<td>Normal or small size</td>
</tr>
<tr>
<td></td>
<td>Valve abnormality?</td>
<td></td>
<td>D-shaped septum</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Pulmonary exam</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lungs</td>
<td>A-line predominance</td>
<td>B-lines</td>
<td>Absent lung sliding?</td>
<td>Consolidation pattern or focal B-lines</td>
</tr>
<tr>
<td>Pleura</td>
<td>Pleural effusion (–)</td>
<td>Bilateral pleural effusions?</td>
<td>Pleural effusion (±)</td>
<td>Pleural effusion (±)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Subpleural consolidations</td>
<td>→ Pneumonia? Emphyema?</td>
</tr>
<tr>
<td>IVC exam</td>
<td>Collapsed IVC</td>
<td>Distended IVC</td>
<td>Distended IVC</td>
<td>Normal or collapsed IVC</td>
</tr>
<tr>
<td>Supplementary exam</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abdomen</td>
<td>Aortic aneurysm</td>
<td>Peritoneal fluid in chronic right</td>
<td>Peritoneal fluid (±)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Aortic dissection</td>
<td>or left heart failure (±)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Intra-abdominal hemorrhage</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vascular</td>
<td>Collapsed veins</td>
<td></td>
<td>Distended internal jugular vein</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>→ Tamponade?</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Femoral, popliteal vein thrombus?</td>
<td></td>
</tr>
</tbody>
</table>

RV, right ventricle; IVC, inferior vena cava.

**Fig. 7.** Stepwise evaluation using the RUSH (Rapid Ultrasound in Shock) protocol to diagnose the category of shock.

Additionally, this approach can help determine if the airways are open and guide procedures like endotracheal intubation and cricothyroidotomy. It can also provide information on lung contusion and limited hemodynamics. Furthermore, it aids in the differential diagnosis of shock and intracranial hypertension. This method even allows for an extensive secondary survey from head to toe [103,105]. The indications for the utility of ultrasound in trauma continue to evolve beyond FAST [106]. FAST-ABCD can be incorporated into advanced trauma life support [107,108]. Evaluation using eFAST can provide critical information during the real-time assessment of patients with complex trauma.

**POCUS IN PEDIATRIC CARE**

Ultrasonography offers real-time imaging without ionizing radiation, making it a safe and effective option in pediatric care [109]. The smaller body sizes, less fat, and thinner abdominal walls of children allow for high-resolution images to be obtained using ultrasonography, which can be used for various diagnostic and orbital, and transcranial ultrasound findings [103–106].
Procedural applications in pediatric emergency care.

Clinical applications of POCUS in pediatric care

Lung and cardiac ultrasound

Ultrasoundography is a highly effective diagnostic tool for diagnosing pneumonia in pediatric patients [110], with available evidence showing its high sensitivity and specificity in identifying pneumonia by detecting B-lines, parenchymal consolidation, and pleural effusion. Similar to that in adults, ultrasoundography can be used to diagnose pneumothorax in pediatric populations. Focused echocardiography can detect pericardial effusion and tamponade, assess global contractility, and evaluate left ventricular function and right ventricular filling [111]. Patients with severely impaired cardiac function on focused echocardiography may be suspected to have myocarditis.

Abdominal and testicular ultrasound

Ultrasoundography can identify the underlying causes of vomiting or acute abdominal pain, which are common symptoms in emergency pediatric patients. Serious diseases such as pyloric stenosis, midgut volvulus, intussusception, and appendicitis can be immediately diagnosed using ultrasound. Furthermore, even novice sonographers can achieve high diagnostic rates for intussusception [112]. In cases of testicular swelling or pain, ultrasound can differentiate between various conditions, such as testicular torsion, torsion of the appendix testis, epididymo-orchitis, and hydrocele. Ultrasonography can be used to determine the structure and vascularity of the testes. A decrease in the blood flow to the testicles indicates testicular torsion [113].

POCUS in trauma

The eFAST has been routinely performed for a long time in patients with chest and abdominal trauma. Unlike in adults, its diagnostic usefulness is limited in children, such that a negative eFAST result in children may not accurately rule out the presence of intra-abdominal injuries [114].

Extremities ultrasound

Ultrasound can be used to detect hip joint effusion in children who visit the hospital with a limping gait. Septic arthritis and transient synovitis can be differentiated through fluid analysis by performing fluid aspiration using ultrasound. Ultrasound can also be a helpful diagnostic tool in detecting fractures in children. Although radiography has been the primary imaging modality used for assessing trauma, ultrasound can be useful for evaluating unossified structures, fractures extending to the unossified epiphyses, occult fractures, physeal separation, intra-articular bodies, ligamentous injuries, and occasionally periosteum trapped between fracture fragments [115].

Clinical applications in ultrasound-guided procedures

Ultrasound-guided procedures enhance the success rate and safety of central venous catheter placements [116,117]. It’s also beneficial for securing peripheral blood vessels, detecting foreign bodies, and performing joint aspirations. When a child gets a splinter or other small foreign body embedded in their skin, ultrasound can help locate the foreign body and guide its removal, reducing the need for more invasive procedures [118].

POCUS IN EMERGENCY CARE

Characteristics of emergency department patients

Emergency department (ED) patients present with a wide range of problems, from critical emergencies to minor issues that can be easily treated. However, we currently lack an advanced medical system to accurately diagnose all patients immediately upon arrival.

Several patients in the ED express their concerns in a disorganized manner. Some patients are unable to communicate due to

<table>
<thead>
<tr>
<th>Fig. 8. Evaluation using SHoC (Sonography in Hypotension and Cardiac Arrest) protocol.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Core view: should be completed</td>
</tr>
<tr>
<td>Cardiac view (subxiphoid and parasternal long axis): pericardial fluid, gross cardiac size, shape and ventricular function</td>
</tr>
<tr>
<td>Lung view (bilateral anterior and lateral chest views): pleural fluid and B-lines</td>
</tr>
<tr>
<td>Inferior vena cava view (subxiphoid or transhepatic view): overall diameter, respiratory variation in size</td>
</tr>
<tr>
<td>2. Supplementary view: if more cardiac information is required</td>
</tr>
<tr>
<td>Other cardiac views (parasternal short axis and apical views): pericardial fluid or cardiac form or function</td>
</tr>
<tr>
<td>3. Additional view: when clinically indicated</td>
</tr>
<tr>
<td>Abdomen–pelvic view: peritoneal fluid</td>
</tr>
<tr>
<td>Aortic view: abdominal aortic aneurysm</td>
</tr>
<tr>
<td>Deep vein thrombosis view</td>
</tr>
</tbody>
</table>
changes in their level of consciousness. Emergency physicians (EP) are trained to gather information from a brief history and physical examination, interpret it as clinical manifestations, and form a hypothesis.

POCUS IN ED

POCUS has become a crucial component of emergency medicine given its ability to improve physical assessments and provide critical information to support or exclude hypotheses at the bedside while awaiting laboratory and imaging results. Attending EPs who appreciate the clinical features of the patient and perform POCUS can effectively enhance patient flow and reduce errors.

The role of EP and POCUS

The role of the EP can be distilled into three primary tasks: stabilization, differential diagnosis, and monitoring (of patient status and procedure). EPs are required to differentiate between critical and noncritical emergencies, stabilize patients, conduct a comprehensive evaluation for differential diagnosis, and determine the most suitable initial treatment. Furthermore, they need to monitor the effectiveness of treatments and utilize ultrasound guidance for procedures. POCUS aids EPs in all these tasks by enhancing safety and accuracy, minimizing errors, and facilitating faster patient flow in the ED [119].

The scope of practice for EM POCUS

In 2009, the ACEP established guidelines for EM POCUS, outlining its scope of practice, which included 11 core applications and five functional clinical categories [120]. These categories encompass resuscitative measures, diagnostic and symptom-based assessments, procedure guidance, and therapeutic monitoring (Fig. 9).

Substantial evidence supports the use of multiorgan POCUS for evaluating and managing patients with cardiopulmonary or hemodynamic failure. POCUS using established protocols, can pro-

---

Fig. 9. The American College of Emergency Physicians (ACEP) 2008 emergency ultrasound guideline.

Fig. 10. Scope of practice of point-of-care ultrasound. Illustration drawn by Won Woong Lee.
Point-of-care ultrasound in critical care and emergency medicine

vide crucial information for swift diagnosis and appropriate management in critical situations that demand immediate attention and intervention to prevent death or serious harm. Such critical situations include cardiac arrest [86,87,121], major torso trauma [99,122], shock [95,97,123,124], respiratory difficulty [29,125,126], chest pain [127–129], and life-threatening abdominal pain. Noncritical situations such as scrotal pain, ocular symptoms, soft tissue or musculoskeletal problems, and noncritical abdominal pain also fall within the scope of EM POCUS (Figs. 10, 11).

While it may be challenging for EPs to provide optimal care for each patient without causing harm, their proficiency with POCUS would undoubtedly enhance patient flow and reduce errors.

POCUS IN CRITICAL CARE

POCUS is commonly used in critical care settings, primarily in the ICU where assessments should be comprehensive rather than urgent. Given that POCUS examinations do not cover the full functional and structural status of patients, comprehensive ultrasound has been commonly used in the ICU. Additionally, it may be challenging for ICU clinicians to master all the specialized and professional skills across various fields. Comprehensive echocardiography requires considerably more image acquisition, proficiency, and experience than POCUS [130]. Thus, ICU clinicians determine whether ultrasound evaluation is needed and link clinical departments with experts.

Many ICU clinicians are well-trained to perform specialized ultrasound studies. Several coronary care intensivists perform comprehensive echocardiography, whereas a few respiratory care intensivists learn lung ultrasound. Hence, ICU clinicians can diagnose critically ill patients quickly and accurately with their acquired abilities. A POCUS study in an ICU is dependent on the skill and experience of the clinician performing the study. Therefore, the scope of examination can vary based on both the clinician and patient admitted to the ICU [24]. Despite comprehensive ultrasound study, pleural effusion, pneumothorax, ascites, and deep vein thrombosis is frequently diagnosed using POCUS [131].

Additionally, intensive care patients may experience sudden exacerbations of preexisting diseases or complications. ICU clinicians should be ready to evaluate and manage any hemodynamic and respiratory deteriorations using POCUS. Regardless of the type of ICU or disease being treated, POCUS is crucial for assessing cardiac function, cardiac tamponade, significant valvular dysfunction, and determining the fluid responsiveness of patients in shock [24]. Given that the heart pumps and beats constantly, assessing its function via the ultrasound can be quite challenging. Acquiring proficiency in echocardiography demands a significant investment of time and effort [131].

Catheterization should always be conducted in an aseptic and safe manner under ultrasound guidance [132]. Furthermore, due to the severity of their conditions, ICU patients often have limited transportation. As a result, drainage catheters are frequently inserted into various thoracic and abdominal organs at the bedside.

POCUS EDUCATION CURRICULUM (STUDENTS AND RESIDENTS)

Although academic hospitals have increasingly adopted POCUS, there remains a wide variability in residency training. The ACEP published the first guideline for emergency ultrasound in 2001 [120], which had been subsequently updated in 2009 and 2014. On the other hand, the International Federation for Emergency Medicine (IFEM) released its POCUS guidelines in 2015 [129]. Both guidelines share similar applications and educational content, but their scope and methods differ. Educational guidelines suitable for medical practice are needed in Korea.
ACEP policy statement
The ACEP categorizes emergency ultrasound into five clinical areas: resuscitation, diagnosis, symptoms, procedure guidance, and therapeutic monitoring. There are 12 core applications for POCUS, including trauma, intrauterine pregnancy, AAA, cardiac, biliary, urinary tract, deep vein thrombosis, musculoskeletal and nerve, thoracic, ocular, bowel, and procedural guidance. The ACEP advocates for an educational curriculum that underscores the reasons for performing emergency ultrasounds and offers hands-on experience [49]. It is crucial to establish standardized training and education curricula for POCUS in areas such as scope of practice, competency training, hospital credentialing, specialty certification, quality control, and leadership in clinical ultrasound [120].

IFEM POCUS curriculum
The IFEM has established guidelines for POCUS training programs, categorizing applications into core and enhanced clinical applications. They emphasize initial introductions through short lectures and gaining experience in imaging acquisition, interpretation, and clinical integration [133].

POCUS training in undergraduate medical education
The first national survey of undergraduate medical education in the United States revealed that ultrasound instruction was offered in 62% of medical schools, predominantly in the third year [134]. According to the most recent national survey in 2020, 69 medical schools have integrated the POCUS into their training curriculum [135]. A study that implemented a 4-year ultrasound curriculum found that its graduates relied more heavily on POCUS than their peers in their respective specialties, and that their POCUS findings often influenced their case management [136].

POCUS training of EM in Korea
In 2021 and 2022, the Society of Emergency and Critical Care Imaging (SECCI) conducted a Delphi survey of 50 specialists in emergency and critical care medicine who used POCUS to identify POCUS applications they should incorporate into their education. The survey showed that domestic guidelines should follow international trends. However, further research is required to ascertain the appropriate level of skill trainees should achieve at different stages of their training.

Beyond acknowledging the significance of POCUS in emergency medical settings, basic ultrasound education also needs to be considered. Several educational methods and guidelines are being developed. At this point, we believe it necessary to establish guidelines for standardizing education in Korea.

FUTURE PERSPECTIVES AND BEYOND
Currently, POCUS helps physicians diagnose and treat patients in real-time. Advances in POCUS have revolutionized EM, critical care, and severe trauma.

Beyond EDs, ICUs, and trauma centers
In various medical settings, POCUS could revolutionize diagnosis and treatment. In the future, POCUS may be applied to primary care clinics, ambulatory surgery centers, patients' homes as well as EDs, ICUs, and trauma centers. As handheld devices become more advanced and lighter, they will become increasingly useful in areas such as prehospital emergency medicine, disaster relief, and war zones, where access to healthcare facilities may be limited.

Future perspectives
POCUS has become a valuable tool for healthcare providers to perform rapid assessments in clinical settings, particularly for neonates and children who may not have easy access to conventional imaging. In many emergency and critical care situations, this device provides real-time imaging and diagnostic capabilities near the patient's bedside, aiding in prompt and accurate diagnosis [137]. As handheld devices become more advanced and lighter, and as equipment and enhanced training programs become available, POCUS is expected to become an integral part of early patient care.

CONCLUSION
POCUS is a versatile and valuable tool in emergency and critical care medicine. It provides real-time clinical information and enhances diagnostic accuracy. With the development of portable ultrasound devices, accessibility has expanded. Various applications of POCUS have demonstrated significant clinical benefits. However, appropriate usage and proper training are crucial to ensure patient safety and reliability. Guidelines and educational curricula are essential for standardizing POCUS training. As technology and training programs continue to advance, the effectiveness of POCUS will only increase.

ETHICS STATEMENT
Not applicable.

CONFLICT OF INTEREST
Yong Soon Cho and Je Hyeok Oh are Editorial Board members of
Clinical and Experimental Emergency Medicine, but were not involved in the peer reviewer selection, evaluation, or decision process of this article. No other potential conflict of interest relevant to this article was reported.

FUNDING

None.

AUTHOR CONTRIBUTIONS

Conceptualization: WC, YSC; Investigation: WWL; Supervision: JHO; Validation: YRH, HL, BSK, YWK, CYK, EJ, YS, HBK, SJK, HK, DS, DHL, JYH, JHL; Writing—original draft: all authors; Writing—review & editing: all authors. All authors read and approved the final manuscript.

ORCID

Wookjin Choi https://orcid.org/0000-0001-8779-0081
Young Soon Cho https://orcid.org/0000-0002-6843-9517
Young Rock Ha https://orcid.org/0000-0002-4889-6550
Je Hyeok Oh https://orcid.org/0000-0002-5211-3838
Heekyung Lee https://orcid.org/0000-0001-5700-3331
Bo Seung Kang https://orcid.org/0000-0002-0792-0198
Yong Won Kim https://orcid.org/0000-0003-0108-8932
Chan Young Koh https://orcid.org/0000-0003-0967-8208
Ji Han Lee https://orcid.org/0000-0003-1972-6170
Euigi Jung https://orcid.org/0000-0001-5194-4720
Youdong Sohn https://orcid.org/0000-0001-8789-0090
Han Bit Kim https://orcid.org/0000-0001-7957-2711
Su Jin Kim https://orcid.org/0000-0003-5769-9647
Hohyun Kim https://orcid.org/0000-0001-9434-8654
Dongbum Suh https://orcid.org/0000-0002-2449-1006
Dong Hyun Lee https://orcid.org/0000-0001-6253-3396
Ju Young Hong https://orcid.org/0000-0003-3416-3054
Won Woong Lee https://orcid.org/0000-0003-0248-9172

REFERENCES

43. Johnston KW, Rutherford RB, Tilson MD, Shah DM, Hollier L,


94. Perera P, Mailhot T, Riley D, Mandavia D. The RUSH exam: rapid ultrasound in shock in the evaluation of the critically
Point-of-care ultrasound in critical care and emergency medicine

Expert opinion on evidence after the 2020 Korean Cardiopulmonary Resuscitation Guidelines: a secondary publication

Sung Phil Chung, Youdong Sohn, Jisook Lee, Youngsuk Cho, Kyoung-Chul Cha, Ju Sun Heo, Ai-Rhan Ellen Kim, Jae Guk Kim, Han-Suk Kim, Hyungoo Shin, Chiwon Ahn, Ho Geol Woo, Byung Kook Lee, Yong Soo Jang, Yu Hyeon Choi, Sung Oh Hwang; on behalf of the Guideline Committee of the Korean Association of Cardiopulmonary Resuscitation (KACPR)

Considerable evidence has been published since the 2020 Korean Cardiopulmonary Resuscitation Guidelines were reported. The International Liaison Committee on Resuscitation (ILCOR) also publishes the Consensus on CPR and Emergency Cardiovascular Care Science with Treatment Recommendations (CoSTR) summary annually. This review provides expert opinions by reviewing the recent evidence on CPR and ILCOR treatment recommendations. The authors reviewed the CoSTR summary published by ILCOR in 2021 and 2022. PICO (patient, intervention, comparison, outcome) questions for each topic were reviewed using a systemic or scoping review methodology. Two experts were appointed for each question and reviewed the topic independently. Topics suggested by the reviewers for revision or additional description of the guidelines were discussed at a consensus conference. Forty-three questions were reviewed, including 15 on basic life support, seven on advanced life support, two on pediatric life support, 11 on neonatal life support, six on education and teams, one on first aid, and one related to COVID-19. Finally, the current Korean CPR Guideline was maintained for 28 questions, and expert opinions were suggested for 15 questions.

Keywords: Heart arrest; Cardiopulmonary resuscitation; Expert opinion

Received: 2 August 2023
Revised: 18 August 2023
Accepted: 20 August 2023

Correspondence to: Sung Oh Hwang
Department of Emergency Medicine, Yonsei University Wonju College of Medicine, 20 Ilsan-ro, Wonju 26426, Korea
Email: shwang@yonsei.ac.kr

INTRODUCTION

The Korean cardiopulmonary resuscitation (CPR) guidelines have been updated periodically since they were first developed in 2006, with the fourth revised version published in 2020 [1]. The International Liaison Committee on Resuscitation (ILCOR) reviews the latest evidence and publishes the Consensus on CPR and Emergency Cardiovascular Care Science with Treatment Recommendation (CoSTR) every 5 years starting in 2005, which is summarized as a practice guideline. The Korean CPR guidelines can be developed based on the CoSTR because the Korean Association of Cardiopulmonary Resuscitation (KACPR) participated in the evidence review process as a member of the Resuscitation Council of Asia, a member organization of the ILCOR [2].

As research and publications in the field of resuscitation have increased, the need to shorten the update cycle of CPR guidelines has increased. Accordingly, the ILCOR has been conducting evidence reviews and publishing CoSTR summaries annually since 2017 [3]. It also releases an annual update of CoSTR summaries since the introduction of the 2020 guidelines [4,5], which can be found on its website (costr.ilcor.org). The Guideline Committee of KACPR concluded that it would be better to review recent evidence and to update the necessary contents before the next revision of the Korean CPR guidelines, which is scheduled for 2025. This review includes expert consensus opinions regarding the evidence on CPR published after the 2020 Korean CPR Guidelines.

EVIDENCE REVIEW METHODOLOGY

The evidence review focused on the topics of the CoSTR summaries published by the ILCOR in 2021 [4] and 2022 [5]. The members of the CPR Guidelines Committee and the evidence reviewers included experts recommended by eight professional organizations related to the CPR guidelines. The committee members and evidence reviewers were experts with experience using the methodology for revising the guidelines, including literature search, systematic review and meta-analysis, and the GRADE (Grading of Recommendations Assessment, Development, and Evaluation) method. Members of the CPR Guidelines Committee selected items that required evidence review among the topics of CoSTR summaries. For review of the topics, the PICO (patient, intervention, comparison, outcome) format was used. For the evidence review, domestic papers as well as papers published in international journals were reviewed. PubMed, Embase, Cochrane Central Register of Controlled Trials (CENTRAL), Education Resources Information Center (ERIC), and KoreaMed were utilized for literature search. Since the 2020 Korean CPR Guidelines included papers published up to September 2020, papers published from October 2020 to May 2023 were included in this review. For topics not covered in the 2020 Korean CPR Guidelines, papers prior to 2020 were also reviewed. The review process used one of three methodologies: systematic review, scoping review, or evidence update. Among the PICO questions on first aid, those unrelated to CPR were excluded. A total of 43 PICO questions was selected for the review, including 15 on basic life support, seven on advanced life support, two on pediatric life support, 11 on neonatal life support, six on education implementation team, one on first aid, and one on COVID-19.

Two experts independently reviewed each PICO question. If one reviewer suggested the need for revision or addition of the 2020 Korean CPR Guidelines, the PICO question was sent to the consensus workshop for discussion and decision (Fig. 1). As a result, new expert consensus opinions were presented for 15 PICO questions (Table 1).
Evidence update after the 2020 Korean CPR Guidelines

**BASIC LIFE SUPPORT**

**Video-based dispatch system**
Several studies have compared CPR quality to evaluate the effectiveness of video-based emergency dispatch systems. However, only two retrospective observational studies reported in Korea [6,7] compared patient survival as an outcome. The implementation of video-based emergency dispatch systems compared to that of the conventional audio-based systems improved the survival-to-discharge rate (22.3% vs. 10.7%; odds ratio [OR], 2.33; P < 0.001) and the rate of good neurological outcomes at discharge (16.0% vs. 6.3%; OR, 2.77; P < 0.001) [8]. The 2020 Korean CPR Guidelines recommend dispatcher-assisted CPR; however, only the use of speaker phones or hands-free functions is recommended during dispatcher-assisted CPR. We recommend implementing a video-based dispatch system for improving the survival rate and neurological outcomes of patients with cardiac arrest.

**CPR during transport**
In an observational study reported from North America [9], the intra-arrest transport group compared with the on-site CPR group had a lower survival-to-discharge rate (4.0% vs. 8.5%; risk difference, 4.6%; range, 0.0%–5.1%) and poor neurological outcomes (2.9% vs. 7.1%; risk difference, 4.2%; range, 3.5%–4.9%). However, it is difficult to generalize this result because the prehospital emergency medical services systems in North America differ from those in Korea in terms of the composition of emergency medical personnel, level of prehospital emergency care, and related legal regulations. The ILCOR suggested that CPR should be performed on-site, except in cases where the need for transport is clear, such as in cases of extracorporeal membrane oxygenation (ECMO) candidates.

The 2020 Korean CPR Guidelines recommend that transfer to the hospital be considered if spontaneous circulation is not restored after 6 minutes of basic life support or 10 minutes of advanced life support at the scene. For CPR during transport, the Guideline Committee decided to maintain current recommendations. During transport to a hospital, high-quality CPR should be maintained.

**In-water resuscitation for individuals who experienced drowning**
In a retrospective observational study [10] comparing a group that received rescue ventilation for 1 minute in water when drowning and another that did not, initial survival (94.7% vs. 37.0%, P < 0.001), survival-to-discharge (87.5% vs. 25%, P = 0.005), and good neurological outcome (52.6% vs. 7.4%, P = 0.001) rates were higher in the group that received rescue ventilation. In-water resuscitation can be considered in situations where adequately trained personnel can use appropriate equipment.

**ECMO for individuals who experienced drowning**
In the 2020 Korean CPR Guidelines, there was no recommendation for the use of ECMO in individuals who experienced drowning. The ILCOR analyzed two retrospective observational studies [11,12] and 11 case reports and stated that ECMO can be consid-
Table 1. Topics reviewed by evidence reviewers

<table>
<thead>
<tr>
<th>Topic</th>
<th>Recommendation summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic life support</td>
<td>Video-based dispatch system We recommend implementing a video-based dispatch system.</td>
</tr>
<tr>
<td>CPR during transport</td>
<td>We recommend that transfer to the hospital be considered if spontaneous circulation is</td>
</tr>
<tr>
<td>In-water resuscitation in drowning</td>
<td>not restored after 6 min of basic life support or 10 min of advanced life support at</td>
</tr>
<tr>
<td>ECMO in drowning</td>
<td>the scene.</td>
</tr>
<tr>
<td>C-A-B or A-B-C in drowning</td>
<td>ECMO may be beneficial in patients with cardiac arrest due to drowning or in patients</td>
</tr>
<tr>
<td></td>
<td>with severe respiratory failure due to drowning.</td>
</tr>
<tr>
<td>Advanced life support</td>
<td>The C-A-B sequence, starting with chest compressions, is recommended for the sequence</td>
</tr>
<tr>
<td>Targeted temperature management after cardiac</td>
<td>of CPR even for a drowning victim.</td>
</tr>
<tr>
<td>arrest</td>
<td></td>
</tr>
<tr>
<td>Vasopressin and corticosteroids for cardiac</td>
<td>We suggest considering using vasopressin and steroid combination therapy during CPR in</td>
</tr>
<tr>
<td>arrest</td>
<td>an IHCA setting.</td>
</tr>
<tr>
<td>Consciousness during CPR</td>
<td>Sedatives, analgesics, or both may be used in very small doses, if possible, to reduce</td>
</tr>
<tr>
<td>CPR and defibrillation in the prone position</td>
<td>pain and suffering in conscious patients during CPR.</td>
</tr>
<tr>
<td>Pediatric life support</td>
<td>CPR can be started in patients in the prone position and a secure airway if the change</td>
</tr>
<tr>
<td>PEWS with or without rapid response teams</td>
<td>to the supine position is not possible.</td>
</tr>
<tr>
<td>Neonatal life support</td>
<td></td>
</tr>
<tr>
<td>Cord management at birth for preterm infants</td>
<td>We suggest delayed cord clamping of 30 sec or longer in preterm infants less than 34</td>
</tr>
<tr>
<td></td>
<td>wk of gestation who do not require resuscitation, and intact cord milking as a</td>
</tr>
<tr>
<td></td>
<td>reasonable alternative to delayed cord clamping in preterm infants between 28 and 33</td>
</tr>
<tr>
<td>Education</td>
<td>wk of gestation.</td>
</tr>
<tr>
<td>Pre-arrest prediction of survival following</td>
<td></td>
</tr>
<tr>
<td>IHCA</td>
<td>The use of these predictive scales in patients with IHCA is not recommended.</td>
</tr>
<tr>
<td>Basic life support training for potential</td>
<td>We recommend that basic life support should be taught to potential rescuers of the</td>
</tr>
<tr>
<td>rescuers for the population at a high risk of</td>
<td>population at high risk of cardiac arrest.</td>
</tr>
<tr>
<td>cord management at birth for preterm infants</td>
<td></td>
</tr>
<tr>
<td>Blended learning for life support education</td>
<td>We recommend developing and implementing a blended form of CPR education in addition</td>
</tr>
<tr>
<td>Faculty development approaches</td>
<td>to the conventional training methods.</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>CPR, cardiopulmonary resuscitation; ECMO,</td>
<td></td>
</tr>
<tr>
<td>extracorporeal membrane oxygenation; C-A-B,</td>
<td></td>
</tr>
<tr>
<td>circulation-airway-breathing; A-B-C,</td>
<td></td>
</tr>
<tr>
<td>airway-breathing-circulation; IHCA, in-</td>
<td></td>
</tr>
<tr>
<td>hospital cardiac arrest; PEWS, Pediatric Early</td>
<td></td>
</tr>
<tr>
<td>Warning Score.</td>
<td></td>
</tr>
</tbody>
</table>

The C-A-B or A-B-C approach in cases of drowning

Nine studies were reviewed; however, none compared the order of CPR in cases of drowning [10,13,14]. The ILCOR suggested, with expert consensus, starting CPR with chest compressions (the C [circulation]-A [airway]-B [breathing] approach) for the layperson, whereas healthcare providers could consider starting rescue ventilation before chest compressions (the A-B-C approach). The 2020 Korean Guidelines do not include recommendations on whether the CPR sequence should be changed depending on circumstances, including drowning. In addition to the suggestion of ILCOR, considering the simplicity and practicality of CPR training, the C-A-B sequence, starting with chest compressions, is recommended for the sequence of CPR even for a drowning victim.

ADVANCED LIFE SUPPORT

TTM after cardiac arrest

In a targeted temperature management (TTM) trial [15] comparing target temperatures of 33 °C versus 36 °C and the TTM2 trial [16] comparing 33 °C versus normothermia below 37.5 °C (fever prevention), no difference was observed in survival to discharge, 180-day survival, or neurological outcomes at 180 days. According to a network meta-analysis [17] comparing the effects of target temperatures in 10 randomized controlled studies, compared
to normothermia (37–37.8 °C), body temperatures of 31–32, 33–34, and 35–36 °C did not improve survival or neurological outcomes. The ILCOR recommended maintaining the body temperature below 37.5 °C because it can reduce the burden on medical personnel and side effects and the use of fever prevention instead of maintaining normothermia [18]. In the TTM2 study, more than 90% of the cardiac arrests were witnessed, and 62% to 63% of initial rhythms were ventricular fibrillation. The characteristics of out-of-hospital cardiac arrest (OHCA) patients in Korea are different from those of patients included in the TTM and TTM2 studies. Compared to patients enrolled in the TTM and TTM2 studies, Korean OHCA patients had a much lower incidence of a shockable rhythm and a longer time from collapse to recovery of spontaneous circulation, which might be associated with a higher chance of a severe post-cardiac arrest syndrome. Therefore, it is necessary to consider differences in the characteristics of cardiac arrest patients in Korea. In the fever prevention group of the TTM2 study [16], acetaminophen and a method of removing clothes and lowering the room temperature were used; temperature control devices were used to control body temperature in 46% of cases. Retrospective studies have suggested that hypothermia can improve neurological outcomes in patients with severe cerebral ischemic injury [19–21]. We recommend that target temperature should be maintained at 32–36 °C for at least 24 hours, as recommended by the 2020 Korean CPR Guidelines.

Vasopressin and corticosteroids for cardiac arrest
Three randomized controlled trials [22–24] including patients with in-hospital cardiac arrest showed that the use of vasopressin and steroids did not improve the survival to discharge rate (OR, 1.39; 95% confidence interval [CI], 0.90–2.14) or rate of good neurological outcomes (OR, 1.64; 95% CI, 0.99–2.72). However, it increased the rate of return of spontaneous circulation (ROSC; OR, 2.09; 95% CI, 1.54–2.84). The ILCOR recommended not using the vasopressin and steroid combination therapy during CPR because it has not been associated with any significant difference in survival, and no study including patients with OHCA has been conducted. The 2020 Korean Guidelines did not provide any recommendations on the combined use of vasopressin and steroids during CPR. Considering that the combination of these drugs increases the ROSC rate and that these drugs are commonly used in hospitals, we suggest vasopressin and steroid combination therapy during CPR in an in-hospital cardiac arrest setting.

Consciousness during CPR
There have been three observational studies; one cross-sectional study; and several case reports on pain, anxiety, agitation, and posttraumatic stress disorder in conscious patients during CPR. The studies reported that they verbally reassured the patients or administered sedatives or neuromuscular blockers [25–49]. Following the results of the scoping review conducted by the ILCOR, we recommend the following: (1) sedatives, analgesics, or both may be used in very small doses, if possible, to reduce pain and suffering in conscious patients during CPR; (2) neuromuscular blocking drugs should not be administered alone to conscious patients; (3) the optimal drug regimen for sedation and analgesia during CPR is unclear, and a regimen commonly used in critically ill patients can be used.

CPR and defibrillation in the prone position
Twenty adult and 12 pediatric cases of cardiac arrest in the prone position have been reported. Most of these cases were observed in the operating room and one case in the intensive care unit [50–68]. There was no significant difference in the rate of ROSC or survival discharge among patients for whom chest compressions were started immediately in the prone position compared with patients for which chest compressions were started after changing the position from prone to supine. Arterial pressure during CPR was higher in the prone position group [69,70]. The end-tidal carbon dioxide partial pressure in five adults and two children was 10 mmHg or higher, and the time interval from collapse to defibrillation was shortened when defibrillation was performed in the prone position [54–56,61,65,71–73]. As recommended by ILCOR, we recommend the following for adults with cardiac arrest in the prone position: (1) if cardiac arrest occurs in the prone position with a secured airway, CPR can be started if change to the supine position is not possible or poses a significant risk to the patient; (2) if cardiac arrest occurs in the prone position without a secure airway, the patient position should be changed to supine and CPR should be initiated as soon as possible; (3) if a patient with cardiac arrest is in the prone position and cannot immediately be placed in the supine position, defibrillation can be attempted in the prone position.

PEDIATRIC LIFE SUPPORT
Pediatric early warning scores and pediatric rapid response teams
One randomized controlled trial [74] and 11 cohort studies [75–85] of pediatric early warning scoring systems or implementation of a pediatric rapid response system were reviewed. The use of the pediatric early warning score tended to reduce the incidence of in-hospital cardiac arrest, mortality, and unexpected clinical deterioration. However, since research on the elements to be in-
included in the pediatric early warning scoring system is lacking, a scoring system that can detect early warning signs of pediatric cardiac arrest, considering the available resources of each hospital, is recommended. Operation of a pediatric rapid response team is associated with a considerable decline in the preintervention trajectory of critical deterioration and a decreased likelihood of respiratory and cardiopulmonary arrest outside of the critical care unit. However, considering that the medical resources and hospital environment of the hospital where the study was conducted were different from those in Korea, the experts decided to make recommendations on the pediatric rapid response team after additional research results in Korea are released.

NEONATAL LIFE SUPPORT

Cord management at birth for preterm infants
According to a systematic review [86] comparing delayed cord clamping and early cord clamping in preterm infants with a gestational age less than 34 weeks, delayed cord clamping resulted in significantly higher hemoglobin and hematocrit within 24 hours after birth and hematocrit at 7 days after birth and lowest mean arterial pressure within 12 hours after birth. Furthermore, the risk of using inotropics due to hypotension and blood transfusions within 24 hours after birth was significantly lower in these infants. When intact cord milking and early cord clamping were compared, hemoglobin and hematocrit levels within 24 hours after birth were significantly higher and the risk of using inotropics due to hypotension and blood transfusions within 24 hours after birth was significantly lower in infants with intact cord milking. On the other hand, comparison of delayed cord clamping and intact cord milking revealed no significant intergroup differences in these parameters. Based on these findings, the 2021 ILCOR CoSTR suggests delayed cord clamping for more than 30 seconds in preterm infants less than 34 weeks of gestational age who do not require immediate resuscitation and intact cord milking as a reasonable alternative to delayed cord clamping in preterm infants between 28 and 33 weeks of gestation. The 2020 Korean CPR Guidelines recommend that umbilical cord milking not be performed in infants less than 28 weeks of gestation due to the increased risk of intraventricular hemorrhage.

We suggest delayed cord clamping of 30 seconds or longer in preterm infants less than 34 weeks of gestation who do not require resuscitation and intact cord milking as a reasonable alternative to delayed cord clamping in preterm infants between 28 and 33 weeks of gestation.

EDUCATION, IMPLEMENTATION, AND TEAM

Pre-arrest prediction of survival following in-hospital cardiac arrest
Pre-arrest clinical prediction rules, such as pre-arrest morbidity, prognosis after resuscitation, and good outcome following attempted resuscitation scores, have been studied for predicting the prognosis of patients with in-hospital cardiac arrest; however, reliable results have not been achieved [87–93]. Therefore, the use of these predictive scales in patients with in-hospital cardiac arrest is not recommended. In addition, since there have been no related studies in pediatric patients, no recommendations can be made regarding the use of prognostic predictive scales for children with in-hospital cardiac arrest.

Basic life support training for potential rescuers of populations at high risk of cardiac arrest
Potential rescuers, such as family members of high-risk patients, are less likely to voluntarily participate in CPR training but are willing to receive training [94,95]. Several studies [94–99] have recommended that basic life support be taught to potential rescuers of high-risk patients for OHCA, and that emergency staff should encourage potential rescuers to participate in basic life support. We recommend that basic life support be taught to potential rescuers of the population at high risk of cardiac arrest.

Blended learning for life support education
Blended learning is an educational method that combines face-to-face and non–face-to-face forms and was introduced in the 2020 Korean CPR Guidelines. Following the COVID-19 pandemic and the development of information technology, the use of various non–face-to-face methods has become more common in medical education [100–102]. Therefore, if resources and conditions allow, it is recommended to develop and implement a blended form of CPR education in addition to the conventional training methods.

Faculty development approach
Continuing CPR education for the public and emergency medical providers is important to increase survival rates after cardiac arrest. To provide continuous CPR training, an instructor training curriculum to teach trainees is important. Although many studies have explained the necessity of CPR instructor training programs, no study has reported that patient outcomes improved with the introduction of the instructor training program [103,104]. Nevertheless, because the instructor training program is an important factor in the teaching method and performance of trainees, it should be introduced.
CONCLUSION

The Korean CPR guidelines are revised every 5 years. Considering the situation in which new evidence continues to be published, it is necessary to update CPR guidelines to reflect the latest evidence between revision cycles. This review summarizes expert opinions based on the CoSTR summary published by the ILCOR since the publication of the 2020 Korean CPR Guidelines. We hope that this review will contribute to improving the survival of patients with cardiac arrest.

ETHICS STATEMENT

Not applicable.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

FUNDING

None.

ACKNOWLEDGMENTS

The authors thank the following members for their role in the Guideline Committee of Korean Association of Cardiopulmonary Resuscitation (KACPR): Do Kyun Kim (Seoul National University Hospital, Seoul, Korea), Jin Tae Kim (Seoul National University Hospital), Mi Jin Lee (Kyungpook National University, Daegu, Korea), Joo Young Lee (Seoul St. Mary's Hospital, College of Medicine, The Catholic University of Korea, Seoul, Korea), Myung Ja Cho (Republic of Korea National Red Cross, Wonju, Korea), Eun Sun Jin (Kyunghee University Hospital at Gangdong, Seoul, Korea), and Seung Tae Han (Republic of Korea Special Warfare School, Seoul, Korea).

AUTHOR CONTRIBUTIONS

Conceptualization: SOH, SPC; Methodology: SOH, SPC; Project administration: SPC; Supervision: SPC; Writing—original draft: YS, JL, YC, KCC, JSH, AREK, JGK, HSK, HS, CA, HGW, BKL, YSJ, YHC; Writing—review & editing: SOH. All authors read and approved the final manuscript.

REFERENCES

5. Wyckoff MH, Greif R, Morley PT, et al. 2022 International Consensus on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Science with Treatment Recommendations: summary from the basic life support; advanced life support; pediatric life support; neonatal life support; education, implementation, and teams; and first aid task forces. Circulation 2022;146:e483–557.
6. Lee HS, You K, Jeon JP, Kim C, Kim S. The effect of video-instructed versus audio-instructed dispatcher-assisted cardio-


91. Hong SI, Kim YJ, Cho YJ, Huh JW, Hong SB, Kim WY. Predictive value of pre-arrest albumin level with GO-FAR score in pa-
98. Han KS, Lee JS, Kim SJ, Lee SW. Targeted cardiopulmonary resuscitation training focused on the family members of high-risk patients at a regional medical center: a comparison between family members of high-risk and no-risk patients. Ulus Travma Acil Cerrahi Derg 2018;24:224–33.
Echocardiographic features of myocardial rupture after acute myocardial infarction on emergency echocardiography

Byung Wook Lee, Yong Sung Cha, Sung Oh Hwang, Yoon-Seop Kim, Sun Ju Kim
Department of Emergency Medicine, Yonsei University Wonju College of Medicine, Wonju, Korea

Objective Myocardial rupture is a fatal complication of acute myocardial infarction (AMI). Early diagnosis of myocardial rupture is feasible when emergency physicians (EPs) perform emergency transthoracic echocardiography (TTE). The purpose of this study was to report the echocardiographic features of myocardial rupture on emergency TTE performed by EPs in the emergency department (ED).

Methods This was a retrospective and observational study involving consecutive adult patients presenting with AMI who underwent TTE performed by EPs in the ED of a single academic medical center from March 2008 to December 2019.

Results Fifteen patients with myocardial rupture, including eight (53.3%) with free wall rupture (FWR), five (33.3%) with ventricular septal rupture (VSR), and two (13.3%) with FWR and VSR, were identified. Fourteen of the 15 patients (93.3%) were diagnosed on TTE performed by EPs. Diagnostic echocardiographic features were found in 100% of the patients with myocardial rupture, including pericardial effusion for FWR and a visible shunt on the interventricular septum for VSR. Additional echocardiographic features indicating myocardial rupture were thinning or aneurysmal dilatation in 10 patients (66.7%), undermined myocardium in six patients (40.0%), abnormal regional motions in six patients (40.0%), and pericardial hematoma in six patients (40.0%).

Conclusion Early diagnosis of myocardial rupture after AMI is possible using echocardiographic features on emergency TTE performed by EPs.

Keywords Myocardial infarction; Complication; Emergency medical services; Echocardiography

What is already known
Emergency physicians can perform echocardiography in acute myocardial infarction (AMI) patients with suspected myocardial rupture. However, information on echocardiographic features of myocardial rupture after AMI is limited.

What is new in the current study
In this retrospective observational study, 93.3% of myocardial ruptures after AMI were diagnosed using emergency echocardiography performed by emergency physicians. The results of this study provide diagnostic and additional echocardiographic features of myocardial rupture detected on emergency echocardiography.
Echocardiography of myocardial rupture after myocardial infarction

INTRODUCTION

Acute myocardial infarction (AMI) complicated by myocardial rupture is often fatal [1]. Myocardial rupture after AMI is generally reported as a subacute complication [2,3] and can occur in the early phase of AMI. If sufficient damage to the myocardium accumulates in the acute phase, myocardial rupture can occur in the early phase of AMI before or at emergency department (ED) arrival.

Clinical manifestations of myocardial rupture may differ based on the location of the injury and hemodynamic consequences. Myocardial rupture includes free wall rupture (FWR) and ventricular septal rupture (VSR), which may result in various significant hemodynamic derangements from the early phase of AMI. The incidence of myocardial rupture reported in clinical studies ranges from 0.31% to 0.45% [2–4]. However, the incidence of myocardial rupture reported on the autopsy of myocardial infarction patients is up to 30.7%, which suggests that a large proportion of myocardial rupture remains undiagnosed [5]. Due to the high mortality rate following myocardial rupture, early diagnosis and prompt surgical treatment are crucial for survival. Therefore, emergency physicians (EPs) should be aware of myocardial rupture during emergency treatment of AMI.

Most current EDs are equipped with echocardiography for immediate performance in AMI patients with suspected myocardial rupture. However, only one report has been published on the early diagnosis of myocardial rupture using echocardiography performed by EPs [6]. The purpose of this study was to investigate the echocardiographic features of myocardial rupture detected by EPs using echocardiography in the ED.

METHODS

Ethics statements

This study was approved by the Institutional Review Board of Wonju Severance Christian Hospital (No. CR319132). The requirement for informed consent from patients was waived due to the retrospective nature of the study.

Study design and setting

This was a retrospective and observational study involving consecutive adult patients (> 18 years of age) presenting with AMI in the ED of a tertiary care hospital from March 2008 to December 2019. The ED has approximately 46,000 annual patient visits and provides emergency care by residents and board-certified EPs. Emergency coronary angiography (CAG) and percutaneous coronary intervention are performed by cardiologists as needed throughout the day. A multifunctional ultrasonography machine, which can perform transthoracic echocardiography (TTE) and transesophageal echocardiography, is available 24 hours a day, 7 days a week in the ED. Emergency echocardiography is performed by EPs. Our training program for emergency echocardiography includes a 4-hour lecture, hands-on practice with an EP and cardiologist (SOH) for 1 month, and a minimum of 150 supervised examinations.

Selection of participants

Electronic medical records of the hospital were reviewed for cases of “MI and FWR or VSR” based on the International Classification of Diseases, 10th Revision (ICD-10) code (I21, AMI; I51.0, acquired cardiac septal defect; I31.2, hemopericardium; I31.3, pericardial effusion; I31.9, disease of the pericardium; I23.0, hemopericardium as current complication following AMI; I23.2, ventricular septal defect as current complication following AMI; and I23.3, rupture of the cardiac wall without hemopericardium as current complication following AMI).

After reviewing the medical records and echocardiographic findings of these patients, those with myocardial rupture observed on echocardiography performed in the ED were included in the study. Patients whose myocardial rupture occurred during in-hospital stay, who had no echocardiographic evidence of myocardial rupture, or who had uninterpretable echocardiographic findings due to poor image quality were excluded.

Diagnosis and echocardiographic findings of myocardial rupture

When patients with suspected MI arrived at the ED, they received emergency cardiac care and underwent TTE performed by the attending EPs. Two ultrasound machines (Vivid E9, General Electric; EPIQ 7, Philips) equipped with 1 to 5 MHz phased array transducers were used in the ED during the study period. Our protocol of emergency echocardiography for patients with suspected AMI includes two-dimensional (2D) images from the parasternal, apical, and subcostal windows and color flow imaging. The initial echocardiographic diagnosis was made by EPs who performed TTE. Real-time consultation with another EP and cardiologist (SOH) was conducted if abnormal findings were observed on bedside echocardiography.

Echocardiographic findings were divided into diagnostic and additional features suggestive of myocardial rupture. Diagnostic features of myocardial rupture included a newly developed pericardial effusion for FWR or a visible shunt on the interventricular septum on 2D echocardiography or color flow imaging for VSR. Additional features suggestive of myocardial rupture were thin-
ning or aneurysmal dilation of the affected myocardium; under-
determined myocardium such as endocardial disruption, ulceration, or
dissection; abnormal wall motions such as fluttering or impinge-
ment; and pericardial hematoma. All acquired images were stored
in a myocardial picture archiving and communication system and
reviewed by an EP and cardiologist. The final diagnosis of myo-
cardial rupture was made using comprehensive echocardiography
by a cardiologist and/or surgical findings. Based on the echocar-
diographic findings, the type, features, and anatomical site of the
rupture were investigated.

Clinical variables
The following clinical variables of patients were obtained from
the medical records: age, sex, vital signs, chief complaint, comor-
bidities, smoking history, Killip classification at ED, area of MI,
surgical operation, year of onset, time from chest pain onset to
ED arrival, type of AMI, pulmonary edema on chest x-ray, left
ventricular ejection fraction, serum troponin I level, cardiac arrest
during a hospital stay, and in-hospital mortality.

Statistical analysis
Data were expressed based on the variable properties. Categorical
data were reported as numbers with percentages for proportions
and compared using Fisher exact test. Continuous data were re-
ported as median (interquartile range) or mean ± standard devia-
tion. Normality was assessed using the Shapiro-Wilk test. All sta-
tistical analyses were performed using IBM SPSS ver. 23.0 (IBM

<table>
<thead>
<tr>
<th>Table 1. Patient characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Characteristic</td>
</tr>
<tr>
<td>Age (yr)</td>
</tr>
<tr>
<td>Male sex</td>
</tr>
<tr>
<td>Systolic blood pressure (mmHg)</td>
</tr>
<tr>
<td>Heart rate (mmHg)</td>
</tr>
<tr>
<td>Chief complaint</td>
</tr>
<tr>
<td>Chest pain</td>
</tr>
<tr>
<td>General weakness</td>
</tr>
<tr>
<td>Time from chest pain onset to ED arrival (hr)</td>
</tr>
<tr>
<td>Comorbidity</td>
</tr>
<tr>
<td>Hypertension</td>
</tr>
<tr>
<td>Diabetes mellitus</td>
</tr>
<tr>
<td>Dyslipidemia</td>
</tr>
<tr>
<td>Prior coronary artery disease</td>
</tr>
<tr>
<td>Smoking history</td>
</tr>
<tr>
<td>Killip class</td>
</tr>
<tr>
<td>I</td>
</tr>
<tr>
<td>II</td>
</tr>
<tr>
<td>III</td>
</tr>
<tr>
<td>IV</td>
</tr>
<tr>
<td>Electrocardiogram</td>
</tr>
<tr>
<td>STEMI</td>
</tr>
<tr>
<td>Non-STEMI</td>
</tr>
<tr>
<td>Infarction area</td>
</tr>
<tr>
<td>Anterior wall</td>
</tr>
<tr>
<td>Inferior wall</td>
</tr>
<tr>
<td>Posterior wall</td>
</tr>
<tr>
<td>Lateral wall</td>
</tr>
<tr>
<td>LVEF in echocardiography</td>
</tr>
<tr>
<td>Pulmonary edema on chest x-ray</td>
</tr>
<tr>
<td>Surgery</td>
</tr>
<tr>
<td>In-hospital cardiac arrest</td>
</tr>
<tr>
<td>In-hospital mortality</td>
</tr>
</tbody>
</table>

Values are presented as mean ± standard deviation, number (%), or median (interquartile range).
ED, emergency department; STEMI, ST-segment elevation myocardial infarction; LVEF, left ventricular ejection fraction.

<table>
<thead>
<tr>
<th>Table 2. Types of myocardial rupture (n=15)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of myocardial rupture</td>
</tr>
<tr>
<td>FWR</td>
</tr>
<tr>
<td>VSR</td>
</tr>
<tr>
<td>Combined (FWR and VSR)</td>
</tr>
</tbody>
</table>

FWR, free wall rupture; VSR, ventricular septal rupture.

<table>
<thead>
<tr>
<th>Table 3. Echocardiographic features of the patients based on the type of myocardial rupture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feature</td>
</tr>
<tr>
<td>Key feature</td>
</tr>
<tr>
<td>Pericardial effusion</td>
</tr>
<tr>
<td>Visible defect</td>
</tr>
<tr>
<td>Additional feature</td>
</tr>
<tr>
<td>Thinning or aneurysm</td>
</tr>
<tr>
<td>Undermined myocardium</td>
</tr>
<tr>
<td>Abnormal regional motions</td>
</tr>
<tr>
<td>Pericardial hematoma</td>
</tr>
</tbody>
</table>

Values are presented as number (%).
FWR, free wall rupture; VSR, ventricular septal rupture.
Fig. 1. Echocardiographic features of myocardial rupture. (A–F) Key features. (G–R) Additional features. (A, B) Pericardial effusion (PE). Parasternal long axis view shows pericardial effusion with diastolic collapse of the right ventricle (RV; arrow) indicating cardiac tamponade in a patient with free wall rupture (FWR). (C–F) Visible defect and shunt. Parasternal short axis view shows a visible defect and shunt flow on the interventricular septum (arrow) in a patient with ventricular septal rupture (VSR). (G, H) Thinning of the myocardium. Parasternal short axis view shows thinning of the interventricular septum (arrow) involved in myocardial rupture in a patient with VSR. (I, J) Aneurysmal dilation. Apical four-chamber view shows an aneurysmal dilation of the apical interventricular septum (arrow) in a patient with combined FWR and VSR. (K, L) False aneurysm. Apical two-chamber view shows undermined myocardium resulting in an aneurysm (arrow) in a patient with FWR. (M, N) Undermined myocardium. Apical long axis view shows dissection of the interventricular septum (arrow) in a patient with VSR. (O, P) Undermined myocardium. Parasternal short axis view shows undermined myocardium resulting in an ulceration (arrow) in a patient with FWR. (Q, R) Pericardial hematoma. Subcostal view shows a pericardial hematoma (arrow) in a patient with FWR. LV, left ventricle; LA, left atrium; RA, right atrium; AO, aorta.
RESULTS

Patient characteristics
A total of 7,475 consecutive patients with AMI who presented to the ED was identified during the study period, and only 87 patients had corresponding diagnostic codes. Among the 87 patients, 62 were not compatible with the diagnosis, five had uninterpretable TTE findings due to poor image quality, and five developed myocardial rupture during the hospital stay and were excluded. Finally, 15 patients were included in the analysis (Supplementary Fig. 1, Supplementary Table 1).

The mean patient age was 73.7 ± 9.8 years, and nine patients (60.0%) were male. Hypertension was the most common comorbidity (seven patients, 46.7%), and only one patient (6.7%) had prior coronary artery disease. Three patients (20.0%) presented with AMI of Killip class IV. The anterior wall was the most common infarct location (53.3%). Four patients (26.7%) underwent surgery. The in-hospital mortality was 86.7% (Table 1).

Echocardiographic diagnosis of myocardial rupture by EPs
Myocardial rupture in 14 patients (93.3%) was diagnosed based on echocardiography performed by EPs. In one patient (6.7%), a diagnosis of VSR in the apical septum was missed. Types of myocardial rupture included FWR in eight patients (53.3%), VSR in five patients (33.3%), and combined rupture of FWR and VSR in two patients (13.3%) (Table 2).

Echocardiographic features of myocardial rupture
Diagnostic echocardiographic features were found in 100% of the patients with myocardial rupture, including pericardial effusion for FWR and a visible shunt on the interventricular septum for VSR. Additional echocardiographic features indicating myocardial rupture were thinning or aneurysmal dilatation in nine patients (60.0%), undermined myocardium in six patients (40.0%), abnormal regional wall motions in six patients (40.0%), and pericardial hematoma in six patients (40.0%) (Table 3, Fig. 1, Supplementary Table 2, Supplementary Video 1). The apical septal area was the most common site involved in myocardial rupture (Fig. 2).

DISCUSSION

In the present study, key echocardiographic features of myocardial rupture including pericardial effusion for FWR or visible shunt on the interventricular septum for VSR as well as various additional echocardiographic features suggestive of myocardial rupture were presented. The noninflammatory process is mostly attributed to myocardial rupture during the first 24 hours after AMI, although both inflammatory and noninflammatory processes, including cardiomyocyte apoptosis or defective myocardial remodeling, can be involved in the pathogenesis of myocardial rupture [7–9]. Marked alteration of the skeletal framework and an acute change in connective tissue in the central zone of AMI may contribute to myocardial rupture [10]. The cardiac skeleton starts to collapse around the ischemic region within hours of myocardial injury from AMI.

Considering the possibility of myocardial rupture early after AMI, EPs should be aware of the potential presence of myocardial rupture.
rupture when performing echocardiography in patients with AMI. For early diagnosis of myocardial rupture, echocardiography should be performed in the ED for all patients presenting with symptoms or signs of infarct extension [11]. However, EPs may miss myocardial ruptures if direct evidence is not observed because routine examination with color Doppler imaging focuses on valvular regurgitation. In the present study, diagnosis of myocardial rupture in the apical septum was missed on echocardiography. The EPs performed echocardiography, including routine examinations of color Doppler imaging on cardiac valves; however, they did not observe the affected area of myocardial rupture. This finding indicates that EPs should closely examine the possibility of mechanical complications when performing echocardiography in patients with AMI. In addition, highly prevalent areas of myocardial rupture including the anterior and inferior walls of the left ventricle, noted in the present as well as previous studies, should be closely observed during emergency echocardiographic examination [4,12, 13]. In the present study, the incidence of FWR was higher than of VSR; however, in a study in which the mechanical complications during hospitalization were investigated, the incidence of VSR was higher than of FWR [14]. In the present study, the mechanical complications of myocardial infarction were investigated in the ED; in the previous studies, mechanical complications were investigated during the entire hospitalization period. The differences in incidence and pattern of mechanical complications are possibly due to the timing of identification of mechanical complications.

The present study provides detailed echocardiographic features of myocardial rupture. Key echocardiographic features of myocardial rupture were pericardial effusion for FWR and shunt flow through the interventricular septum for VSR. Additional echocardiographic findings suggestive of myocardial rupture may be accompanied by key echocardiographic features such as thinning or aneurysmal dilation of the affected myocardium; undermined myocardium, including endocardial disruption, ulceration, or dissection; and abnormal wall motions, including fluttering or impingement. Therefore, if additional echocardiographic features suggestive of myocardial rupture are observed, EPs should closely examine for myocardial rupture using color Doppler imaging to the affected area during emergency echocardiography.

The echocardiographic features observed in the present study are relatively consistent with the pathological classification of myocardial rupture, which is classified as follows. Type I is an abrupt tear in the wall without thinning; type II involves erosion of the infarcted myocardium covered by a thrombus; and type III is marked thinning of the myocardium and secondary formation of an aneurysm with a central perforation [15]. Type I myocardial rupture can be observed as a visible defect with shunt flow on echocardiography. Type II myocardial rupture can be observed as undermined myocardium including endocardial disruption or ulceration. Type III myocardial rupture is compatible with thinning or aneurysmal dilation with or without a shunt flow on echocardiography. However, autopsy findings may not match the echocardiographic features observed in vivo.

The present study has several limitations. It was a retrospective observational study conducted at a single institution with a relatively small sample size. Due to the nature of the study in which patients were retrospectively selected using ICD-10 codes, cases were possibly missed. Because the skills of an EP to perform echocardiography may vary by institution, limitations may exist in the general application of our experience to all emergency centers. Because only four of 15 patients underwent cardiac surgery due to death from in-hospital cardiac arrest or refractory shock, the relationship between the pattern of mechanical complications and prognosis was unknown. Because patients with mechanical complications undergo rapid deterioration of clinical status, the need for early diagnosis cannot be overemphasized. Autopsy on deceased patients could not be performed to confirm the diagnosis, preventing matching of the echocardiographic findings with pathological features of myocardial rupture.

In summary, the results of the present study showed that myocardial rupture, including FWR and VSR, can be observed with various findings on emergency echocardiography. EPs should be aware of the echocardiographic features suggestive of myocardial rupture for early diagnosis in the ED to help determine life-saving procedures such as pericardiocentesis or emergency cardiac surgery.

SUPPLEMENTARY MATERIALS

Supplementary Fig. 1. Flowchart of the patient enrollment.
Supplementary Table 1. Clinical characteristics of the patients
Supplementary Table 2. Echocardiographic features
Supplementary Video 1. Individual echocardiographic movies of myocardial rupture.
Supplementary materials are available from https://doi.org/10.15441/ceem.23.037.

ETHICS STATEMENT

This study was approved by the Institutional Review Board of Wonju Severance Christian Hospital (No. CR319132). The requirement for informed consent from patients was waived due to the retrospective nature of the study.
CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

FUNDING

None.

AUTHOR CONTRIBUTIONS

Conceptualization: YSC, SOH; Data curation: YSK, SJK; Formal analysis: BWL, YSC; Visualization: YSC, SOH; Writing-original draft: BWL, YSC, SOH; Writing-review & editing: all authors. All authors read and approved the final manuscript.

ORCID

Byung Wook Lee https://orcid.org/0009-0000-6344-9188
Yong Sung Cha https://orcid.org/0000-0001-9897-4273
Sung Oh Hwang https://orcid.org/0000-0003-4585-3181
Yoon-Seop Kim https://orcid.org/0000-0001-5929-4291
Sun Ju Kim https://orcid.org/0000-0002-8169-5750

REFERENCES

An expert consensus–based checklist for quality appraisal of educational resources on adult basic life support: a Delphi study

Alexei Birkun¹, Adhish Gautam², Bernd W. Böttiger³; the Delphi Study Investigators⁴

¹Department of General Surgery, Anesthesiology, Resuscitation and Emergency Medicine, Medical Academy named after S.I. Georgievsky of V.I. Vernadsky Crimean Federal University, Simferopol, Russia
²Regional Government Hospital, Una, India
³Department of Anesthesiology and Intensive Care Medicine, Faculty of Medicine, University Hospital Cologne, University of Cologne, Cologne, Germany
⁴The full list of the Delphi Study Investigators is listed in the Acknowledgments

Objective Given the lack of a unified tool for appraising the quality of educational resources for lay-rescuer delivery of adult basic life support (BLS), this study aimed to develop an appropriate evaluation checklist based on a consensus of international experts.

Methods In a two-round Delphi study, participating experts completed questionnaires to rate each item of a predeveloped 72-item checklist indicating agreement that an item should be utilized to evaluate the conformance of an adult BLS educational resource with resuscitation guidelines. Consensus on item inclusion was defined as a rating of ≥ 7 points from ≥ 75% of experts. Experts were encouraged to add anonymous suggestions for modifying or adding new items.

Results Of the 46 participants, 42 (91.3%) completed the first round (representatives of 25 countries with a median of 16 years of professional experience in resuscitation) and 40 (87.0%) completed the second round. Thirteen of 72 baseline items were excluded, 55 were included unchanged, four were included after modification, and four new items were added. The final checklist comprises 63 items under the subsections “safety” (one item), “recognition” (nine items), “call for help” (four items), “chest compressions” (12 items), “rescue breathing” (12 items), “defibrillation” (nine items), “continuation of CPR” (two items), “choking” (10 items) and “miscellaneous” (four items).

Conclusion The produced checklist is a ready-to-use expert consensus–based tool for appraising the quality of educational content on lay-rescuer provision of adult BLS. The checklist gives content developers a tool to ensure educational resources comply with current resuscitation knowledge, and may serve as a component of a prospective standardized international framework for quality assurance in resuscitation education.

Keywords Cardiopulmonary resuscitation; Education; Checklist; Standards; Airway obstruction

This is an Open Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (https://creativecommons.org/licenses/by-nc/4.0/).
INTRODUCTION

A lack of knowledge and skills in cardiopulmonary resuscitation (CPR) and related fears of causing harm are major barriers to attempting to resuscitate a person who has suffered a cardiac arrest [1,2]. Effective education in resuscitation improves levels of confidence and the willingness of bystanders to perform CPR in actual cardiac arrest situations [3]. Interventions aimed at increasing the penetration of CPR training in communities reportedly enhance the likelihood of bystanders performing CPR and improve neurological outcomes and survival rates after an out-of-hospital cardiac arrest [4,5]. Training of laypeople in resuscitation is strongly endorsed by the scientific community [6–8].

In spite of the importance of widespread dissemination of resuscitation training, the prevalence of CPR knowledge among the general public is low in many regions of the world [9]. For people who have no opportunity to attend traditional instructor-led CPR training, self-directed CPR learning is currently recommended as a reasonable alternative [6]. Various digital resuscitation-training resources, including videos, online courses, computer games, and smartphone apps, are available for public use. However, studies have shown that the educational content of such resources often does not adhere to resuscitation guidelines based on state-of-the-art resuscitation knowledge and evidence-based cardiac arrest management practices [10–12]. Suboptimal guideline compliance has been also revealed in certified instructor–led basic life support (BLS) courses [13,14].

Although it is apparent that a standardized framework for systematic quality control and quality assurance for educational resources on resuscitation is necessary [15], no unified tool for evaluating the quality of educational content on resuscitation currently exists. This study aimed to develop an expert consensus–based checklist for appraising the quality of educational resources on lay-rescuer delivery of adult BLS.

METHODS

The Delphi survey technique, a method of obtaining general consensus on a particular topic based on expert opinions collected through a series of structured questionnaires or “rounds,” was used taking into account published practical guidance [16,17].

Expert recruitment

An informational letter explaining the study design and its aims was sent to experts, who were invited to participate through the European Resuscitation Council (ERC) Research NET, an international, interdisciplinary, and interprofessional group for the study of cardiac arrest and resuscitation [18]. Prospective participants were asked in an online questionnaire to provide data on their field of specialization, highest academic degree, number of years of professional experience in resuscitation, availability of provider or instructor certification(s) in CPR, familiarity with international resuscitation guidelines (self-rated on a 10-point Likert scale from 1 [not familiar at all] to 10 [have a thorough knowledge of]), prior participation in Delphi studies, country of residence, and affirm their willingness to participate by completing an electronic consent form using a Google form (Google LLC). All participating experts were asked if they wished to be acknowledged in the final publication. No limitations to the number or geographic location of participants were applied. Participating experts were blinded to each other’s participation throughout the study.

Delphi procedure

A two-round Delphi exercise was carried out to create a consen-
sus-based checklist. Each round was conducted over a 2-week period. Within each round, two email reminders were sent to non-responders (on day 5 and day 11). If no response was received from an expert within the 2-week period, one additional attempt to obtain results was made immediately after the deadline in the form of a third email reminder.

In the first round, experts were asked via email to review a baseline checklist (Supplementary Material 1) and complete an offline questionnaire (Microsoft Excel table, Microsoft Corp), rating each checklist item by answering the following question “How much do you agree that this item should be utilized as part of the checklist for evaluating conformance of an adult BLS educational resource with resuscitation guidelines?” For the rating, a 9-point Likert scale was applied ranging from 1 (totally disagree) to 9 (totally agree). Experts were encouraged to add anonymous free-text comments and suggestions for modifying, removing, or adding new checklist items.

The baseline checklist (Supplementary Material 1) [12] was based on the 2020 International Consensus on CPR [19], ERC Guidelines 2021 [20], and ERC COVID-19 Guidelines [21] as a rework of the original structured 36-item checklist by Jensen et al. [14]. The baseline checklist contained 72 items grouped in 11 thematic subsections, including “safety” (one item), “recognition” (10 items), “call for help” (four items), “chest compressions” (11 items), “rescue breathing” (12 items), “defibrillation” (eight items), “continuation of CPR” (two items), “recovery position” (three items), “choking” (10 items), “COVID-19” (six items), and “miscellaneous” (five items).

Results of the first round were analyzed by applying the following criteria. Items that received the rating of ≥ 7 points from ≥ 75% of experts were considered to have reached the consensus threshold for inclusion. Items on which expert consensus was achieved were subjected to a second round of evaluation without exclusion and were added to the final checklist. All other items were excluded. After the analysis, all experts received a report with the final results.

Data that support findings of this study, including tables with a summary of anonymized expert ratings and comments, calculated quantitative expert-group results, modifications to the checklist, and blank questionnaire forms, are openly available in the Mendeley Data repository as a dataset [22]. As the study used nonsensitive and anonymized data, it did not require ethical approval and received an institutional review board exemption.

**Statistical analysis**

Data analysis was carried out with IBM SPSS ver. 26 (IBM Corp) and involved descriptive statistics (median, interquartile range [IQR], and absolute and relative values).

**RESULTS**

A total of 46 individuals initially agreed to participate in the study. Of these, 42 (91.3%) completed the first round (in November 2022) and 40 (87.0%) completed the second round (in December 2022). Characteristics of participants who completed the first round are provided in Table 1. The expert group represented 25 countries on six continents. Most participants (n = 35, 83.3%) reported specializing in anesthesiology and/or intensive (critical) care and/or emergency medicine. Almost a third (31.0%) held a research doctoral degree (n = 12) or a higher-level doctorate (n = 1). The number of years of professional experience in resuscitation varied from 2 to 40 years (median, 16 years; IQR, 10–28 years). Most participants (n = 35, 83.3%) were certified as BLS providers and 30 (71.4%) were BLS instructors. The median self-rating of familiarity with international resuscitation guidelines (American Heart Association Guidelines, ERC Guidelines, International Consensus on CPR) on a 10-point scale was 9 (IQR, 9–10). Previous participation in a Delphi study was reported by 22 participants (52.4%).

In the first round, the median percentage of experts who assigned an item a rating of ≤ 3 points was 21% (IQR, 11%–29%); ≥ 75% of experts on a 9-point scale was 25% (IQR, 20%–40%). The median percentage of experts who gave an item a rating of ≥ 7 points was 22% (IQR, 15%–30%).
No items reached the consensus threshold for exclusion in the first round, 57 items reached the consensus threshold for inclusion and were carried forward to the second round unchanged, and 15 items did not reach the consensus threshold for inclusion or exclusion and were subjected to the second round. Of those 15 items, nine items were modified according to experts’ comments (see dataset [22]). Following experts’ suggestions, seven new items were added to the checklist.

The second round began with 79 items. In that round, the median percentage of experts who assigned an item a rating of ≤3 points was 5% (IQR, 0%–10%; range, 0%–28%) and the median percentage of experts who gave an item ≥7 points was 85% (IQR, 78%–93%; range, 45%–100%). The participating experts agreed to accept the majority of the items covering essential components of adult BLS, including safety considerations, recognition of cardiac arrest, call for help, chest compressions and rescue breathing techniques, use of an automated external defibrillator, help in choking, and miscellaneous questions. In the second round, 66 items reached the consensus threshold for inclusion (Table 2) (see dataset [22]) and the other 13 items did not reach the consensus threshold for inclusion and were excluded. Of these 13 items, two and four items represented essential elements and the majority

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>No. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Country of residence</td>
<td></td>
</tr>
<tr>
<td>Australia</td>
<td>1 (2.4)</td>
</tr>
<tr>
<td>Austria</td>
<td>1 (2.4)</td>
</tr>
<tr>
<td>Belgium</td>
<td>1 (2.4)</td>
</tr>
<tr>
<td>Canada</td>
<td>1 (2.4)</td>
</tr>
<tr>
<td>Cyprus</td>
<td>2 (4.8)</td>
</tr>
<tr>
<td>Denmark</td>
<td>1 (2.4)</td>
</tr>
<tr>
<td>France</td>
<td>2 (4.8)</td>
</tr>
<tr>
<td>Germany</td>
<td>5 (11.9)</td>
</tr>
<tr>
<td>Greece</td>
<td>4 (9.5)</td>
</tr>
<tr>
<td>India</td>
<td>1 (2.4)</td>
</tr>
<tr>
<td>Italy</td>
<td>3 (7.1)</td>
</tr>
<tr>
<td>Malta</td>
<td>1 (2.4)</td>
</tr>
<tr>
<td>Norway</td>
<td>1 (2.4)</td>
</tr>
<tr>
<td>Peru</td>
<td>1 (2.4)</td>
</tr>
<tr>
<td>Poland</td>
<td>1 (2.4)</td>
</tr>
<tr>
<td>Russia</td>
<td>3 (7.1)</td>
</tr>
<tr>
<td>Saudi Arabia</td>
<td>1 (2.4)</td>
</tr>
<tr>
<td>Serbia</td>
<td>1 (2.4)</td>
</tr>
<tr>
<td>Slovenia</td>
<td>2 (4.8)</td>
</tr>
<tr>
<td>South Africa</td>
<td>1 (2.4)</td>
</tr>
<tr>
<td>Spain</td>
<td>1 (2.4)</td>
</tr>
<tr>
<td>Sri Lanka</td>
<td>1 (2.4)</td>
</tr>
<tr>
<td>Switzerland</td>
<td>2 (4.8)</td>
</tr>
<tr>
<td>UK</td>
<td>3 (7.1)</td>
</tr>
<tr>
<td>USA</td>
<td>1 (2.4)</td>
</tr>
<tr>
<td>Field of specialization</td>
<td></td>
</tr>
<tr>
<td>Anesthesiology</td>
<td>6 (14.3)</td>
</tr>
<tr>
<td>Anesthesiology and emergency medicine</td>
<td>1 (2.4)</td>
</tr>
<tr>
<td>Anesthesiology and intensive care</td>
<td>3 (7.1)</td>
</tr>
<tr>
<td>Anesthesiology, intensive care, and emergency medicine</td>
<td>1 (2.4)</td>
</tr>
<tr>
<td>Anesthesiology, intensive care, and medical education</td>
<td>1 (2.4)</td>
</tr>
<tr>
<td>Anesthesiology and medical education</td>
<td>1 (2.4)</td>
</tr>
<tr>
<td>Anesthesiology, resuscitation, and emergency medicine</td>
<td>1 (2.4)</td>
</tr>
<tr>
<td>Cardiac anesthesia and resuscitation education</td>
<td>1 (2.4)</td>
</tr>
<tr>
<td>Cardiology</td>
<td>2 (4.8)</td>
</tr>
<tr>
<td>Critical care nursing education</td>
<td>1 (2.4)</td>
</tr>
<tr>
<td>Critical care and prehospital emergency medicine</td>
<td>1 (2.4)</td>
</tr>
<tr>
<td>Emergency medicine</td>
<td>7 (16.7)</td>
</tr>
<tr>
<td>Emergency medicine and intensive care nursing</td>
<td>1 (2.4)</td>
</tr>
<tr>
<td>Emergency medicine and intensive care</td>
<td>1 (2.4)</td>
</tr>
<tr>
<td>Health economics</td>
<td>1 (2.4)</td>
</tr>
<tr>
<td>Intensive care</td>
<td>5 (11.9)</td>
</tr>
<tr>
<td>Intensive care and pedagogy</td>
<td>1 (2.4)</td>
</tr>
<tr>
<td>Internal medicine</td>
<td>1 (2.4)</td>
</tr>
<tr>
<td>Internal medicine, intensive care, emergency medicine</td>
<td>1 (2.4)</td>
</tr>
<tr>
<td>Lifesaving, BLS, and physical education</td>
<td>1 (2.4)</td>
</tr>
<tr>
<td>Medical education and emergency medicine</td>
<td>1 (2.4)</td>
</tr>
<tr>
<td>Nursing</td>
<td>1 (2.4)</td>
</tr>
<tr>
<td>Nursing, science, and education</td>
<td>1 (2.4)</td>
</tr>
<tr>
<td>Prehospital care and critical care retrieval</td>
<td>1 (2.4)</td>
</tr>
</tbody>
</table>

Table 1. Characteristics of experts participating in the first round of the Delphi survey (n=42)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>No. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highest academic (professional) degree</td>
<td></td>
</tr>
<tr>
<td>Bachelor of Medicine and Bachelor of Surgery</td>
<td>2 (4.8)</td>
</tr>
<tr>
<td>Critical care assistant</td>
<td>1 (2.4)</td>
</tr>
<tr>
<td>Doctor of Medical Science</td>
<td>1 (2.4)</td>
</tr>
<tr>
<td>Doctor of Medicine</td>
<td>19 (45.2)</td>
</tr>
<tr>
<td>Doctor of Philosophy</td>
<td>12 (28.6)</td>
</tr>
<tr>
<td>Master of Medical Education</td>
<td>2 (4.8)</td>
</tr>
<tr>
<td>Master of Science</td>
<td>3 (7.1)</td>
</tr>
<tr>
<td>Master of Science in Nursing</td>
<td>1 (2.4)</td>
</tr>
<tr>
<td>Registered nurse</td>
<td>1 (2.4)</td>
</tr>
</tbody>
</table>

Provider certification

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>No. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BLS</td>
<td>35 (83.3)</td>
</tr>
<tr>
<td>ALS</td>
<td>35 (83.3)</td>
</tr>
<tr>
<td>PALS</td>
<td>11 (26.2)</td>
</tr>
<tr>
<td>Absent</td>
<td>4 (9.5)</td>
</tr>
</tbody>
</table>

Instructor certification

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>No. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BLS</td>
<td>30 (71.4)</td>
</tr>
<tr>
<td>ALS</td>
<td>31 (73.8)</td>
</tr>
<tr>
<td>PALS</td>
<td>8 (19)</td>
</tr>
<tr>
<td>Absent</td>
<td>6 (14.3)</td>
</tr>
</tbody>
</table>

Experience of participation in Delphi studies

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>No. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>22 (52.4)</td>
</tr>
<tr>
<td>No</td>
<td>20 (47.6)</td>
</tr>
</tbody>
</table>

BLS, basic life support; ALS, advanced life support; PALS, pediatric advanced life support.
Table 2. Checklist items based on results of the second round

<table>
<thead>
<tr>
<th>Checklist item</th>
<th>Experts who rated ≥ 7 points (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Safety</strong></td>
<td></td>
</tr>
<tr>
<td>Does the resource state that the rescuer should make sure that he/she, victim, and any bystanders are safe?</td>
<td>100</td>
</tr>
<tr>
<td>Does the resource instruct to use personal protective equipment (e.g., face mask, gloves) if available?</td>
<td>70</td>
</tr>
<tr>
<td><strong>Recognition</strong></td>
<td></td>
</tr>
<tr>
<td>Is cardiac arrest defined as a state when a person is unresponsive with absent or abnormal (agonal) breathing?</td>
<td>93</td>
</tr>
<tr>
<td>Response check: does the resource instruct to shake gently by shoulders and ask loudly to examine if the victim is responsive?</td>
<td>95</td>
</tr>
<tr>
<td>Victim’s position: does the resource instruct to position the victim on their back if unresponsive?</td>
<td>83</td>
</tr>
<tr>
<td><strong>Airway opening</strong></td>
<td></td>
</tr>
<tr>
<td>Is there instruction for head tilt maneuver?</td>
<td>90</td>
</tr>
<tr>
<td>Is there instruction for chin lift maneuver?</td>
<td>90</td>
</tr>
<tr>
<td><strong>Breathing check</strong></td>
<td></td>
</tr>
<tr>
<td>Does the resource instruct to look for breathing?</td>
<td>93</td>
</tr>
<tr>
<td>Is it clear that the rescuer should use a maximum of 10 sec to check breathing?</td>
<td>88</td>
</tr>
<tr>
<td><strong>Agonal breathing</strong></td>
<td></td>
</tr>
<tr>
<td>Does the resource state that agonal breathing should be interpreted a sign of cardiac arrest?</td>
<td>93</td>
</tr>
<tr>
<td>Does the resource describe agonal breathing pattern (e.g., infrequent, slow, noisy gasps, labored breathing)?</td>
<td>83</td>
</tr>
<tr>
<td>Seizure-like activity: does the resource state that seizure-like activity could be a sign of cardiac arrest?</td>
<td>58</td>
</tr>
<tr>
<td><strong>Call for help</strong></td>
<td></td>
</tr>
<tr>
<td>Call EMS</td>
<td></td>
</tr>
<tr>
<td>Does the resource state that the rescuer should immediately ask a helper to call EMS or call themselves when recognising cardiac arrest?</td>
<td>98</td>
</tr>
<tr>
<td>Does the resource instruct to use speaker function (hands-free) on a telephone to start CPR whilst talking to a dispatcher?</td>
<td>88</td>
</tr>
<tr>
<td>Send for AED</td>
<td></td>
</tr>
<tr>
<td>Does the resource instruct to ask a helper to collect nearest AED?</td>
<td>93</td>
</tr>
<tr>
<td>Does the resource state that the rescuer should not leave the victim to collect AED themselves (excepting cases when the rescuer is alone and AED is located close at hand)?</td>
<td>80</td>
</tr>
<tr>
<td><strong>Chest compression</strong></td>
<td></td>
</tr>
<tr>
<td>Does the resource instruct to start compressions as soon as possible?</td>
<td>98</td>
</tr>
<tr>
<td>Rescuer’s position</td>
<td></td>
</tr>
<tr>
<td>Does the resource instruct the rescuer to position themselves next to (by the side of) the victim?</td>
<td>83</td>
</tr>
<tr>
<td>Does the resource instruct to keep arms straight?</td>
<td>100</td>
</tr>
<tr>
<td>Does the resource instruct the rescuer to position themselves vertically above the victim’s chest?</td>
<td>100</td>
</tr>
<tr>
<td>Firm surface: does the resource instruct to perform compressions on a firm surface if it is possible and not time-demanding?</td>
<td>78</td>
</tr>
<tr>
<td>Hand position</td>
<td></td>
</tr>
<tr>
<td>Does the resource instruct to place the heel of one hand at the centre of the chest (lower half of the breastbone)?</td>
<td>98</td>
</tr>
<tr>
<td>Does the resource instruct to place the heel of other hand on top of the first hand and interlock fingers?</td>
<td>80</td>
</tr>
<tr>
<td>Compressions depth: does the resource state the correct depth is 5–6 cm?</td>
<td>95</td>
</tr>
<tr>
<td>Compressions rate: does the resource state the correct rate is 100–120 per minute?</td>
<td>100</td>
</tr>
<tr>
<td>Chest recoil: does the resource instruct to ensure chest recoil after each compression (release pressure on the chest without losing contact with the chest)?</td>
<td>95</td>
</tr>
<tr>
<td>Minimization of pauses: does the resource state that any pauses in chest compressions should be minimized?</td>
<td>98</td>
</tr>
<tr>
<td>Rescuer change: does the resource state that if possible rescuers should change over about every 2 minutes (without interrupting chest compressions) to prevent a decrease in compression quality due to rescuer fatigue?</td>
<td>83</td>
</tr>
<tr>
<td><strong>Rescue breathing</strong></td>
<td></td>
</tr>
<tr>
<td>Compression to ventilation ratio: does the resource instruct to use compression to ventilation ratio of 30:2?</td>
<td>98</td>
</tr>
<tr>
<td>Airway opening</td>
<td></td>
</tr>
<tr>
<td>Is it clear that the rescuer should open airways again prior to ventilation?</td>
<td>90</td>
</tr>
<tr>
<td>Does the resource instruct to maintain head tilt and chin lift during rescue breathing?</td>
<td>83</td>
</tr>
<tr>
<td>Nasal pinch: does the resource instruct to pinch the nose prior to ventilation?</td>
<td>80</td>
</tr>
<tr>
<td>Sealing: does the resource instruct to place lips around the victim’s mouth ensuring airtight seal?</td>
<td>80</td>
</tr>
<tr>
<td>Ventilations</td>
<td></td>
</tr>
<tr>
<td>Does the resource state that each rescue breath should last about 1 second?</td>
<td>75</td>
</tr>
</tbody>
</table>

(Continued on the next page)
Table 2. (Continued)

<table>
<thead>
<tr>
<th>Checklist item</th>
<th>Experts who rated ≥ 7 points (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Does the resource instruct to give a normal breath volume (avoid excessive ventilation)?</td>
<td>78</td>
</tr>
<tr>
<td>Does the resource instruct to look for chest rise?</td>
<td>90</td>
</tr>
<tr>
<td>Does the resource state that the rescuer should take mouth away and turn their head towards the victim's chest to allow and check for passive exhalation?</td>
<td>78</td>
</tr>
<tr>
<td>Does the resource instruct to give a total of two rescue breaths?</td>
<td>90</td>
</tr>
<tr>
<td>Resume compressions: does the resource instruct to resume compressions immediately after the second breath (even if breaths are ineffective)?</td>
<td>93</td>
</tr>
<tr>
<td>Minimum pause: does the resource state that compressions shouldn’t be interrupted for more than 10 sec to deliver two rescue breaths?</td>
<td>85</td>
</tr>
<tr>
<td>Defibrillation</td>
<td></td>
</tr>
<tr>
<td>Turn AED on: does the resource instruct to turn on AED as soon as it arrives?</td>
<td>95</td>
</tr>
<tr>
<td>Attach electrodes: does the resource instruct to attach electrodes to the victim's bare chest?</td>
<td>93</td>
</tr>
<tr>
<td>Remove electrodes protection: does the resource instruct to remove protective film from electrodes before attaching them to the victim's chest?</td>
<td>45</td>
</tr>
<tr>
<td>Electrodes position: does the resource describe correct position for electrodes on the victim's chest?</td>
<td>85</td>
</tr>
<tr>
<td>Continue CPR: does the resource instruct to continue CPR whilst AED is prepared if more than one rescuer is present?</td>
<td>95</td>
</tr>
<tr>
<td>Follow instructions: is it clear that rescuers should follow spoken and visual instructions of AED?</td>
<td>95</td>
</tr>
<tr>
<td>Do not touch</td>
<td></td>
</tr>
<tr>
<td>Analysis: it is clear that bystanders cannot be in physical contact with the victim during analysis?</td>
<td>93</td>
</tr>
<tr>
<td>Shock: it is clear that bystanders cannot be in physical contact with the victim when applying shock?</td>
<td>93</td>
</tr>
<tr>
<td>Resume CPR: does the resource state that after shock (or if no shock is advised) the rescuer should immediately resume CPR and continue as directed by AED?</td>
<td>98</td>
</tr>
<tr>
<td>Minimum pause: does the resource state that long pauses in compressions should be avoided when applying and using AED?</td>
<td>88</td>
</tr>
<tr>
<td>Continuation of CPR</td>
<td></td>
</tr>
<tr>
<td>Does the resource state that CPR should be continuous until a professional tells to stop, the rescuer is exhausted or the victim recovers?</td>
<td>93</td>
</tr>
<tr>
<td>Does the resource describe signs of victim's recovery (waking up, moving, opening eyes and for sure breathing normally)?</td>
<td>75</td>
</tr>
<tr>
<td>Recovery position</td>
<td></td>
</tr>
<tr>
<td>Does the resource instruct to place the victim in recovery position if the victim is breathing normally but unresponsive?</td>
<td>73</td>
</tr>
<tr>
<td>Does the resource describe correct technique for placing the victim in recovery position?</td>
<td>68</td>
</tr>
<tr>
<td>Does the resource instruct to continuously monitor normal breathing for the victim placed in recovery position?</td>
<td>88</td>
</tr>
<tr>
<td>Choking</td>
<td></td>
</tr>
<tr>
<td>Recognition</td>
<td></td>
</tr>
<tr>
<td>Does the resource instruct to suspect choking if someone is suddenly unable to speak or talk, particularly if eating?</td>
<td>78</td>
</tr>
<tr>
<td>Does the resource instruct to ask the conscious victim &quot;Are you choking?&quot;?</td>
<td>63</td>
</tr>
<tr>
<td>Call for help: does the resource state that the rescuer should immediately ask a helper to call EMS or call themselves when recognising severe choking?</td>
<td>80</td>
</tr>
<tr>
<td>Coughing: does the resource instruct to encourage coughing when the victim is conscious and able to cough?</td>
<td>85</td>
</tr>
<tr>
<td>Back blows</td>
<td></td>
</tr>
<tr>
<td>Does the resource instruct to give up to five back blows if coughing fails to clear the obstruction or the victim starts to show signs of fatigue?</td>
<td>88</td>
</tr>
<tr>
<td>Does the resource describe correct technique for back blows?</td>
<td>85</td>
</tr>
<tr>
<td>Abdominal thrusts</td>
<td></td>
</tr>
<tr>
<td>Does the resource instruct to give up to five abdominal thrusts if back blows are ineffective?</td>
<td>80</td>
</tr>
<tr>
<td>Does the resource describe correct technique for abdominal thrusts?</td>
<td>78</td>
</tr>
<tr>
<td>Continue blows and thrusts: does the resource instruct to continue series of five back blows followed by five abdominal thrusts if prior measures are ineffective?</td>
<td>73</td>
</tr>
<tr>
<td>Start CPR: does the resource instruct to start CPR when the victim is unconscious with absent or abnormal breathing?</td>
<td>95</td>
</tr>
<tr>
<td>Look for and remove foreign material: does the resource instruct to look for a foreign material in the victim’s mouth and if visible, remove it?</td>
<td>73</td>
</tr>
<tr>
<td>Avoid blind finger sweep: does the resource state that blind finger sweep should be avoided?</td>
<td>88</td>
</tr>
<tr>
<td>Aftercare: is it clear that the victim successfully treated with abdominal thrusts or chest compressions should be examined by a qualified healthcare practitioner?</td>
<td>75</td>
</tr>
<tr>
<td>Epidemic outbreak situation (e.g., COVID-19)</td>
<td></td>
</tr>
<tr>
<td>Does the resource provide guidance on CPR in epidemic outbreak situations (e.g., during COVID-19 pandemic)?</td>
<td>75</td>
</tr>
<tr>
<td>Recognition: does the resource instruct to avoid opening airways and placing face next to the victims’ mouth or nose for breathing check?</td>
<td>63</td>
</tr>
<tr>
<td>Compression-only CPR: does the resource state that lay rescuers should consider compression-only CPR and AED?</td>
<td>83</td>
</tr>
</tbody>
</table>

(Continued on the next page)
of items of the “recovery position” and “epidemic outbreak situations” (originally, COVID-19) subsections of the checklist, respectively. A decision was therefore made to exclude these subsections (including three items that reached consensus for inclusion). Consequently, 63 items were retained for the final checklist (Supplementary Material 2), including 55 unchanged baseline items, four modified items and four new items, under the subsections “safety” (one item), “recognition” (nine items), “call for help” (four items), “chest compressions” (12 items), “rescue breathing” (12 items), “defibrillation” (nine items), “continuation of CPR” (two items), “choking” (10 items), and “miscellaneous” (four items).

DISCUSSION

Educational efficiency and implementation of resuscitation science are key determinants of survival after cardiac arrest [23]. Turning scientific evidence into practice, in turn, depends on the effectiveness of translating knowledge drawn from resuscitation guidelines through education [8,24].

Although considerable efforts are being made by resuscitation researchers to improve educational efficiency by implementing optimal instructional designs and strategies for teaching resuscitation [6,8], relatively little attention has been paid to quality control of the educational content [15]. Studies have shown that training programs and educational resources on resuscitation commonly do not comply with relevant guidelines, omit core evidence-based recommendations, or incorrectly present essential learning elements [10–14]. This suggests a need to address the issue systematically by establishing a standardized international framework for quality control and quality assurance in resuscitation education [10].

The current study is a step toward realizing this goal. It represents the first attempt to generate a checklist for appraising the quality of educational resources on BLS using an international expert opinion consensus achieved through the Delphi technique. The use of a validated consensus-generating method, involvement of a large number of experts with extensive experience in resuscitation, and high participation rate support the robustness of the study results.

A blank template for “The ERC Research NET structured checklist for quality appraisal of educational resources on adult basic life support” is available online [22]. We propose using the checklist to ensure full coverage of essential issues of lay-rescuer delivery of adult BLS in a syllabus of resuscitation-training resources and to guarantee adherence of educational content to state-of-the-art understanding of effective techniques for resuscitation. The checklist could be utilized by resource developers designing new educational programs and materials, or to bring existing resources into agreement with current evidence-based resuscitation knowledge. The checklist is a ready-to-use tool for conducting research involving expert-led systematic evaluation of the quality of face-to-face courses or electronic training resources on BLS (including online courses, videos, and mobile apps) in terms of compliance with resuscitation guidelines. In particular, such research could help create a collection of reliable, free-of-charge, web-based, or downloadable multimedia resources that could be recommended for mass distribution and therefore contribute to improve worldwide availability and dissemination of high-quality learning materials.
public education on resuscitation.

Future steps include testing of the checklist for interrater and intrarater reliability, translation of the checklist into different languages, and updating the checklist as new resuscitation research evidence becomes available. The expert consensus procedure employed in this study could be used to produce similar instruments for appraising educational programs and resources on pediatric BLS, adult and pediatric ALS, and various aspects of first aid.

This study has limitations to be acknowledged. Given that the checklist was based on the International Consensus on CPR [19] and the ERC Guidelines [20,21], its content may not correspond fully with national guidelines that have country-specific peculiarities. Therefore, before using the checklist to evaluate conformance of adult BLS educational resources with national guidelines, the checklist may need to be adjusted accordingly.

In summary, this study utilized a validated expert consensus technique to create a 63-item structured checklist for appraising the quality of educational content on lay-rescuer delivered adult BLS. Widespread use of the checklist by developers of educational programs and resources on BLS should improve compliance with current evidence-based knowledge on resuscitation and contribute to enhanced educational efficiency. The checklist could be incorporated into a standardized international framework for quality control and quality assurance in resuscitation education.

**SUPPLEMENTARY MATERIALS**

**Supplementary Material 1.** Baseline checklist for evaluating educational resources on lay rescuer adult BLS in terms of compliance with international resuscitation guidelines.

**Supplementary Material 2.** Final expert consensus-based checklist for evaluating educational resources on lay rescuer adult BLS in terms of compliance with international resuscitation guidelines. Supplementary materials are available from https://doi.org/10.15441/ceem.23.049

**ETHICS STATEMENT**

Not applicable.

**CONFLICT OF INTEREST**

Bernd W. Böttiger is board member and treasurer of the European Resuscitation Council (ERC), chairman of the German Resuscitation Council (GRC), federal state doctor of the German Red Cross, member of the Advanced Life Support (ALS) Task Force of the International Liaison Committee on Resuscitation (ILCOR), board member of the German Interdisciplinary Association for Intensive Care and Emergency Medicine (DIVI), founder of the German Resuscitation Foundation, founder of the ERC Research NET, co-editor of Resuscitation, editor of Notfall+Rettungsmedizin, and co-editor of the Brazilian Journal of Anesthesiology. He received fees for lectures from the following companies: Forum für medizinische Fortbildung (FomF), Baxalta Deutschland GmbH, ZOLL Medical Deutschland GmbH, C.R. Bard GmbH, GS Elektromedizinische Geräte G. Stemple GmbH, Novartis Pharma GmbH, Philips GmbH Market DACH, and Bioscience Valuation BSV GmbH. No other potential conflict of interest relevant to this article was reported.

**FUNDING**

None.

**ACKNOWLEDGMENTS**

The full list of the Delphi Study Investigators (in alphabetical order): Abdulmajeed Solaiman Khan (Saudi Resuscitation Council, Pan Arab Resuscitation Council, Mecca, Saudi Arabia); Ahmed Elshaer (Department of Accident and Emergency, University Hospital Ayr, Ayr, Scotland, UK); Amber V. Hoover (American Heart Association, Dallas, TX, USA); Anastasia Spartaninou (School of Medicine, University of Crete, Giosfakia, Greece; Emergency Department, University Hospital of Heraklion, Heraklion, Greece); Andrea Scapigliati (Università Cattolica S. Cuore, Institute of Anesthesiology and Intensive Care, Fondazione Policlinico Universitario A. Gemelli, IRCCS, Rome, Italy); Artem Kuzovlev (Federal Research and Clinical Center of Intensive Care Medicine and Rehabilitation, Moscow, Russia); Baljit Singh (Department of Anesthesiology, Faculty of Medicine and Health Sciences, SGT University, Gurugram, India); Clare Morden (Department of Intensive Care Medicine, Salisbury District Hospital, Salisbury, UK); Cristian Abelairas-Gómez (CLINURSID Research Group; Faculty of Education Sciences, Universidad de Santiago de Compostela, Santiago de Compostela, Spain); Daniel Meyran (Bataillon de Marins Pompiers, Groupement santé, Marseille, France); Daniel Schroeder (Central Hospital of the German Armed Forces, Koblenz, Germany); Daniil O. Starostin (Federal Research and Clinical Center of Intensive Care Medicine and Rehabilitation, Moscow, Russia); David Stanton (Netcare, Johannesburg, South Africa); Eirik Alnes Buanes (Haukeland University Hospital, Bergen, Norway); Ekaterina A. Boeva (Federal Research and Clinical Center of Intensive Care Medicine and Rehabilitation, Moscow, Russia); Enrico Baldi (Division of Cardiology, Fondazione IRCCS Policlinico San Matteo, Pavia, Italy); Evtanthis Georgiou (Education Sector, Nursing Services, Ministry of Health,
Nicosia, Cyprus); Jacqueline Eleonora Ek (Emergency Department, Mater Dei Hospital, Malta); Jan Breckwoldt (University Hospital Zurich, Institute of Anesthesiology, Zurich, Switzerland); Jan Wnent (University Hospital Schleswig-Holstein, Institute for Emergency Medicine, Kiel, Germany); Jessica Grace Rogers (Physician Response Unit, London's Air Ambulance, Barts Health NHS Trust, London, UK); Kasper G. Lauridsen (Department of Medicine, Randers Regional Hospital, Randers, Denmark); Łukasz Szarpak (Institute of Outcomes Research, Maria Skłodowska-Curie Medical Academy, Warsaw, Poland); Marios Georgiou (American Medical Center, Nicosia, Cyprus); Nadine Rott (Department of Anesthesiology and Intensive Care Medicine, University Hospital of Cologne, Cologne, Germany); German Resuscitation Council, Ulm, Germany); Nilmini Wijesuriya (Colombo North Teaching Hospital, Ragama, Sri Lanka); Nino Fijačko (University of Maribor, Faculty of Health Sciences, Maribor, Slovenia); Olympia Nikolaidou (EMS–National Center for Emergency Care (EKAB), Thessaloniki, Greece); Pascal Cassan (International Federation Of Red Cross and Red Crescent National Societies, Paris, France); Peter Paal (Department of Anesthesiology and Intensive Care Medicine, St. John of God Hospital, Paracelsus Medical University, Salzburg, Austria); Peter T. Morley (University of Melbourne, Royal Melbourne Hospital, Melbourne, Australia); Raffo Escalante-Kanashiro (Instituto Nacional de Salud del Niño, Lima, Peru); Robert Greif (University of Bern, Bern, Switzerland; School of Medicine, Sigmund Freud University Vienna, Vienna, Austria); Sabine Nabecker (Department of Anesthesiology and Pain Medicine, Sinai Health System, University of Toronto, Toronto, Canada); Simone Savastano (Division of Cardiology, Fondazione IRCCS Policlinico San Matteo, Pavia, Italy); Theodoros Aslanidis (Intensive Care Unit, St. Paul (“Agios Pavlos”) General Hospital, Thessaloniki, Greece); Violetta Raffay (Department of Medicine, School of Medicine, European University Cyprus, Nicosia, Cyprus); Vlasis Karageorgos (School of Medicine, University of Crete, Giofırakia, Greece); Department of Anesthesiology, University Hospital of Heraklion, Heraklion, Greece); Wolfgang A. Wetsch (Department of Anesthesiology and Intensive Care Medicine, University Hospital of Cologne, Faculty of Medicine, University of Cologne, Cologne, Germany); Željko Malić (First Aid Department, Slovenian Red Cross, Ljubljana, Slovenia).

AUTHOR CONTRIBUTIONS

Conceptualization: AB; Data curation: all authors; Formal analysis: AB, AG; Investigation: all authors; Methodology: AB, AG, BWB; Project administration: AB, BWB; Supervision: AB; Validation: AB, AG; Writing–original draft: AB; Writing–review & editing: AG, BWB, the Delphi Study Investigators. All authors read and approved the final manuscript.

ORCID

Alexei Birkun https://orcid.org/0000-0002-2789-9760
Adhish Gautam https://orcid.org/0000-0001-6900-717X
Bernd W. Böttiger https://orcid.org/0000-0001-8000-8931

REFERENCES

10. Metelmann B, Metelmann C, Schuffert L, Hahnenkamp K, Brinkrolf P. Medical correctness and user friendliness of available
apps for cardiopulmonary resuscitation: systematic search combined with guideline adherence and usability evaluation. JMIR Mhealth Uhealth 2018;6:e190.


22. Birkun A, Gautam A, Bottiger B. Dataset of the Delphi study on development of an expert consensus-based checklist for quality appraisal of educational resources on adult Basic Life Support [Internet]. Mendeley Data; 2023 [cited 2023 Apr 21]. Available from: https://doi.org/10.17632/kjzvzt8b7h.1


Objective Multiple trauma is associated with a remarkable risk of in-hospital complications, which harm healthcare services and patients. This study aimed to assess the incidence of post-trauma complications, their relationship with poor outcomes, and the effect of the Injury Severity Score (ISS) on their occurrence.

Methods This retrospective cohort study was conducted at a pair of trauma centers, between January 2020 and December 2022. All hospitalized adult patients with multiple trauma were included in this study. Multivariable logistic regression was used to identify factors related to post-trauma complications.

Results Among 727 multiple trauma patients, 90 (12.4%) developed in-hospital complications. The most frequent complications were pneumonia (4.8%), atelectasis (3.7%), and superficial surgical site infection (2.5%). According to multivariable logistic regression, ISS, the length of stay in the intensive care unit (ICU), the length of stay in the hospital, and mortality were significantly associated with complications. The complication rate increased by 17% with every single-unit increase in ISS (adjusted odds ratio [OR], 1.17; 95% confidence interval [CI], 1.00–1.38). Per every 1-day increase in the ICU or hospital stay, the complication rate increased by 65% (adjusted OR, 1.65; 95% CI, 1.00–2.73) and 20% (adjusted OR, 1.20; 95% CI, 1.03–1.41), respectively. Posttrauma complications were also significantly more common in patients with mortality (adjusted OR, 163.30; 95% CI, 3.04–8,779.32). In multiple trauma patients with a higher ISS, the frequency, severity, and number of complications were significantly increased.

Conclusion In-hospital complications in multiple trauma patients are frequent and associated with poor outcomes and mortality. ISS is an important factor associated with posttrauma complications.

Keywords Wounds and injuries; Multiple trauma; Trauma severity indices; Complications
INTRODUCTION

Trauma is a serious public health issue ranked as the first cause of disability-adjusted life-years for people of productive age, according to the latest Global Burden of Disease report [1]. Trauma is recognized as blunt or penetrating injuries, mostly from motor vehicle collisions, falls, interpersonal violence, or self-harm. Trauma accounts for approximately one out of three emergency department visits in the United States annually [2]. Undoubtedly, these numbers are likely higher in developing countries due to the lack of infrastructure [3].

During the last decades, the improvement in diagnostic strategies and patient management has led to a remarkable decline in the mortality rate of patients with trauma injuries. Numerous studies have affirmed the improvement in trauma survival rates among patients from different regions [4–7]. However, it is important to note that keeping trauma patients with major injuries alive makes them susceptible to trauma-related complications [8]. Patients with trauma can experience a wide range of in-hospital complications, including infections, coagulopathy, thromboembolic events, and organ failure.

Trauma-related complications bear undesirable consequences for patients and trauma centers. Patients with posttrauma complications have an increased risk of death [9–11]. Moreover, studies have concluded that these individuals experience a more extended hospital stay length and a higher cost of care [12,13]. Such complications can also negatively affect patients’ quality of life and lifelong functionality [14]. Therefore, more attention should be given to reduce the numbers of these unwanted complications.

The majority of trauma-related complications can be prevented. Applying suitable antimicrobial prophylaxis, adhering to venous thromboembolism–prevention guidelines, and practicing early rehabilitation could be practical and effective steps to decrease posttrauma complications. Nevertheless, it should be noted that complications are not similarly distributed among trauma patients.

Based on the existing evidence, there is no way to accurately predict when, how, or what kind of complications a patient with trauma might experience. Conducting more research on the epidemiology of posttrauma complications using records from different trauma centers could help to identify patients at a higher risk.

Therefore, the aims of the present study were the following: (1) assess the overall incidence and types of complications in hospitalized adult patients with multiple trauma; (2) describe the clinical features and outcome of the patients with posttrauma complications; and (3) examine the effect of injury severity on the occurrence of complications in multiple trauma patients.

METHODS

Ethics statement
The study protocol was reviewed and approved by the Institutional Review Board of Shahid Beheshti University of Medical Sciences (No. IR.SBMU.MSP.REC.1400.814). The requirement for informed consent from individual patients was waived due to the retrospective nature of the study. The study adheres to the principles outlined in the Declaration of Helsinki.

Study setting and design
This was a retrospective cohort study evaluating the occurrence of complications in patients with multiple trauma. The study was conducted at a pair of trauma centers (Shohadaye Tajrish Hospital, Tehran, Iran; Valiasr Hospital, Tehran, Iran). Multiple trauma patients were identified from the electronic databases of the centers between January 2020 and December 2022, using the International Classification of Diseases, 10th Revision (ICD-10) code T07. Patients were required to have injuries in two or more areas of the body to be classified as multiple trauma patients [15]. The confidentiality of data was maintained throughout the study, and the results were reported anonymously.
Participants
All patients with multiple trauma aged ≥18 years and hospitalized in the centers mentioned above were included in this study. Patients were excluded if they met the following criteria: (1) admitted as a secondary admission from another center; (2) discharged or transported from the study center before completing the assessment and management; (3) admitted multiple times for one episode of trauma; or (4) died in the emergency department due to the impact of fatal trauma.

Data collection
We collected data from patients’ records, including general demographics (sex, age, comorbidities, and medication history), trauma characteristics (type, mechanism, and Injury Severity Score [ISS]), arrival vital signs (blood pressure, heart rate, respiratory rate, temperature, oxygen saturation, and Glasgow Coma Scale Score [GCS]), management approaches (hemorrhagic shock and transfusion of blood products), hospital admission information (department of admission, mechanical ventilation, length of hospital stay, and intensive care unit [ICU] admission and length of stay), in-hospital complications, and mortality.

To weigh the comorbid conditions and underlying disease, we used the Charlson Comorbidity Index score [16]. The ISS score was measured as the sum of squares of the highest Abbreviated Injury Scale from three different body regions [17]. Posttrauma complications were defined as medical and surgical complications related to trauma that occurred during hospital admission, including infections, thromboembolic events, and circulation disturbance, and were confirmed by two experts and written in the medical records. We classified the complications that were potentially life-threatening or resulted in permanent disability, including cerebral vascular accident, acute coronary syndrome, arrhythmia, abdominal compartment syndrome, pulmonary embolism, acute respiratory distress syndrome, gastrointestinal bleeding, peritonitis, compartment syndrome, deep vein thrombosis, deep surgical site infection, sepsis, and multiorgan failure, as major complications. A general practitioner was responsible for data collection under the direct supervision of an emergency physician specialist.

Statistical analysis
Assuming the frequency of 5% for posttrauma complications based on a previous report [18], for a desired precision of 2%, a minimum sample size of 450 was necessary to estimate complications in our study centers. Therefore, we decided to collect data on patients with multiple trauma during 2 subsequent years. Results of the descriptive analysis are presented as counts with percentages (qualitative variables) or median with interquartile range values (quantitative variables) according to the non-normal distribution of the data. The chi-squared test was used for proportions and the Mann-Whitney U-test was used for continuous variables to compare the demographic and clinical characteristics between the cohort of patients with and without complications, respectively. Any variable with a significant univariable test was inserted into the multivariable logistic regression to find factors related to posttrauma complications. Adjusted odds ratios (ORs) for these factors were presented with 95% confidence intervals (CIs). To further evaluate the association between ISS and the occurrence of posttrauma complications, we used ISS as a categorical variable divided as ≤ 8 (minor), 9 to 15 (moderate), 16 to 24 (severe), and ≥ 25 (very severe) [19]. The impact of ISS on frequency, severity, and the number of complications was assessed using the chi-squared test. All hypothesis tests performed were two-sided. P < 0.05 was considered to be statistically significant. All statistical analyses were conducted using IBM SPSS ver. 24 (IBM Corp).

RESULTS

Characteristics of the study population
Of the 1,336 patients recorded as having multiple trauma in the database between January 2020 and December 2022, there were 890 hospitalized patients (the remaining 446 were managed as outpatients). Among them, 727 patients met the study inclusion criteria (Fig. 1). Patients were admitted to different units of the hospitals, including the emergency department (62.5%), surgery department (19.9%), neurosurgery department (4.5%), and orthopedic surgery department (3.9%), or directly to the ICU (4.4%).

The median age of patients was 33 years (interquartile range [IQR], 24–45 years), and 79.1% of patients were male. Among the total study population, 15.7% had at least one comorbid condition.

Fig. 1. Flow diagram of patient selection. ED, emergency department.
tion, and the median Charlson Comorbidity Index score of these patients was 2 (IQR, 0–3). The trauma type in most patients was blunt (97.2%). The most common causes of trauma were motorcycle accident (28.5%), car accident (27.2%), fall (18.3%), pedestrian accident (17.9%), and assault (6.2%). The median ISS score of all patients was 3 (IQR, 0–9). The overall mortality rate of the whole cohort was 5.8%.

Incidence of complications
A total of 90 patients (12.4%) experienced in-hospital complications during the course of this study, including 35 (38.9%) who suffered from major complications. Most of the patients developed only one complication. The most frequent complications were pneumonia (4.8%), atelectasis (3.7%), and superficial surgical site infection (2.5%). The mortality rate in multiple trauma patients with complications was 33.3%, and a rise in complication numbers (OR, 34.54; 95% CI, 15.77–75.67) and major complications (OR, 4.63; 95% CI, 3.21–6.69) increased the mortality rate. The characteristics of complications observed in this study are demonstrated in Table 1.

The comparison between patients with and without complications revealed a significant difference in age between the two groups (39.5 [IQR, 28.7–51.0] years vs. 32.0 [IQR, 24.0–45.0] years, \( P = 0.005 \)). Patients with complications had higher Charlson Comorbidity Index scores (0 [IQR, 0–1] vs. 0 [IQR, 0–0], \( P = 0.006 \)). The ISS was greater in patients with complications than in those without them (22 [IQR, 14–34] vs. 1 [IQR, 0–6], \( P < 0.001 \)). The presence of complications in multiple trauma patients was associated with ICU admission (54.4% vs. 6.3%, \( P < 0.001 \)), a longer length of ICU stay (3 days [IQR, 2–8 days] vs. 2 days [IQR, 1–3 days], \( P < 0.001 \)) and longer length of hospital stay (5 days [IQR, 2–13 days] vs. 1 day [IQR, 1–1 days], \( P < 0.001 \)), and mortality (33.3% vs. 1.9%, \( P < 0.001 \)). Features of the multiple trauma patients with and without complication are presented in greater detail in Table 2.

A multivariable logistic regression analysis was performed to identify factors associated with complications in patients with multiple trauma (Table 3). Accordingly, ISS, ICU length of stay, hospital length of stay, and mortality were significantly associated with complications. Per every 1-point increase in ISS, the complication rate in multiple trauma patients increased by 17%. Also, with every 1-day increase in the ICU and hospital stay lengths, the complication rate increased by 65% and 20%, respectively. Posttrauma complications were also 163 times more common in patients with mortality.

Effects of injury severity
We further investigated the effects of ISS on in-hospital complica-

### Table 1. The frequency of different complications in patients with multiple trauma (n=727)

<table>
<thead>
<tr>
<th>Variable</th>
<th>No. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of complications</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>46 (6.3)</td>
</tr>
<tr>
<td>2</td>
<td>26 (3.6)</td>
</tr>
<tr>
<td>3</td>
<td>7 (1.0)</td>
</tr>
<tr>
<td>4</td>
<td>3 (0.4)</td>
</tr>
<tr>
<td>5</td>
<td>4 (0.6)</td>
</tr>
<tr>
<td>6</td>
<td>2 (0.3)</td>
</tr>
<tr>
<td>7</td>
<td>1 (0.1)</td>
</tr>
<tr>
<td>8</td>
<td>1 (0.1)</td>
</tr>
<tr>
<td>Central nervous system</td>
<td></td>
</tr>
<tr>
<td>Diabetes insipidus</td>
<td>1 (0.1)</td>
</tr>
<tr>
<td>Cerebral vascular accident</td>
<td>1 (0.1)</td>
</tr>
<tr>
<td>Meningitis</td>
<td>1 (0.1)</td>
</tr>
<tr>
<td>Circulation</td>
<td></td>
</tr>
<tr>
<td>Acute coronary syndrome</td>
<td>7 (1.0)</td>
</tr>
<tr>
<td>Arrhythmia</td>
<td>4 (0.6)</td>
</tr>
<tr>
<td>Acute kidney injury</td>
<td>17 (2.3)</td>
</tr>
<tr>
<td>Abdominal compartment syndrome</td>
<td>1 (0.1)</td>
</tr>
<tr>
<td>Respiratory</td>
<td></td>
</tr>
<tr>
<td>Atelectasis</td>
<td>27 (3.7)</td>
</tr>
<tr>
<td>Pneumonia</td>
<td>35 (4.8)</td>
</tr>
<tr>
<td>Pulmonary embolism</td>
<td>10 (1.4)</td>
</tr>
<tr>
<td>ARDS and respiratory failure</td>
<td>5 (0.7)</td>
</tr>
<tr>
<td>Gastroenterology</td>
<td></td>
</tr>
<tr>
<td>Gastrointestinal bleeding</td>
<td>4 (0.6)</td>
</tr>
<tr>
<td>Hyperbilirubinemia and liver failure</td>
<td>2 (0.3)</td>
</tr>
<tr>
<td>Peritonitis</td>
<td>1 (0.1)</td>
</tr>
<tr>
<td>Bone and joints</td>
<td></td>
</tr>
<tr>
<td>Compartment syndrome</td>
<td>3 (0.4)</td>
</tr>
<tr>
<td>Deep vein thrombosis</td>
<td>3 (0.4)</td>
</tr>
<tr>
<td>Rhabdomyolysis</td>
<td>15 (2.1)</td>
</tr>
<tr>
<td>Coagulation (thrombocytopenia and coagulation disorder)</td>
<td>9 (1.2)</td>
</tr>
<tr>
<td>Infection</td>
<td></td>
</tr>
<tr>
<td>Superficial surgical site infection</td>
<td>18 (2.5)</td>
</tr>
<tr>
<td>Deep surgical site infection</td>
<td>6 (0.8)</td>
</tr>
<tr>
<td>Sepsis</td>
<td>4 (0.6)</td>
</tr>
<tr>
<td>Multiorgan failure</td>
<td>4 (0.6)</td>
</tr>
</tbody>
</table>

ARDS, acute respiratory distress syndrome.
<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Total (n = 727)</th>
<th>Complication</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>33.0 (24.0–45.0)</td>
<td>32.0 (24.0–45.0)</td>
<td>39.5 (28.7–51.0)</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>575 (79.1)</td>
<td>499 (78.3)</td>
<td>76 (84.4)</td>
</tr>
<tr>
<td>Female</td>
<td>152 (20.9)</td>
<td>138 (21.7)</td>
<td>14 (15.6)</td>
</tr>
<tr>
<td>Charlson Comorbidity Index</td>
<td>0 (0–0)</td>
<td>0 (0–0)</td>
<td>0 (0–1)</td>
</tr>
<tr>
<td>Trauma type</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blunt</td>
<td>707 (97.2)</td>
<td>620 (97.3)</td>
<td>87 (96.7)</td>
</tr>
<tr>
<td>Penetrating</td>
<td>20 (2.8)</td>
<td>17 (2.7)</td>
<td>3 (3.3)</td>
</tr>
<tr>
<td>Trauma mechanism</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Car</td>
<td>198 (27.2)</td>
<td>170 (26.7)</td>
<td>28 (31.1)</td>
</tr>
<tr>
<td>Motorcycle</td>
<td>207 (28.5)</td>
<td>192 (30.1)</td>
<td>15 (16.7)</td>
</tr>
<tr>
<td>Pedestrian</td>
<td>130 (17.9)</td>
<td>113 (17.7)</td>
<td>17 (18.9)</td>
</tr>
<tr>
<td>Fall</td>
<td>133 (18.3)</td>
<td>108 (17.0)</td>
<td>25 (27.8)</td>
</tr>
<tr>
<td>Assault</td>
<td>45 (6.2)</td>
<td>42 (6.6)</td>
<td>3 (3.3)</td>
</tr>
<tr>
<td>Other</td>
<td>14 (1.9)</td>
<td>12 (1.9)</td>
<td>2 (2.2)</td>
</tr>
<tr>
<td>Injury Severity Score</td>
<td>3 (0–9)</td>
<td>1 (0–6)</td>
<td>22 (14–34)</td>
</tr>
<tr>
<td>Systolic blood pressure (mmHg)</td>
<td>115 (110–125)</td>
<td>116 (110–125)</td>
<td>110 (100–120)</td>
</tr>
<tr>
<td>Diastolic blood pressure (mmHg)</td>
<td>75 (70–80)</td>
<td>75 (70–80)</td>
<td>70 (60–80)</td>
</tr>
<tr>
<td>Heart rate (beats/min)</td>
<td>81 (78–89)</td>
<td>80 (76–88)</td>
<td>88 (80–100)</td>
</tr>
<tr>
<td>Respiratory rate (breaths/min)</td>
<td>17 (16–18)</td>
<td>17 (16–18)</td>
<td>18 (16–19)</td>
</tr>
<tr>
<td>Oxygen saturation (%)</td>
<td>97 (96–98)</td>
<td>97 (96–98)</td>
<td>96 (94–98)</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>36.8 (36.5–37.0)</td>
<td>36.8 (36.5–37.0)</td>
<td>37.0 (36.5–37.1)</td>
</tr>
<tr>
<td>Glasgow Coma Scale score</td>
<td></td>
<td></td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>13–15</td>
<td>618 (97.0)</td>
<td>67 (74.4)</td>
<td>685 (94.2)</td>
</tr>
<tr>
<td>9–12</td>
<td>10 (1.6)</td>
<td>11 (12.2)</td>
<td>21 (2.9)</td>
</tr>
<tr>
<td>6–8</td>
<td>5 (0.8)</td>
<td>5 (5.6)</td>
<td>10 (1.4)</td>
</tr>
<tr>
<td>4–5</td>
<td>1 (0.2)</td>
<td>4 (4.4)</td>
<td>5 (0.7)</td>
</tr>
<tr>
<td>&lt;3</td>
<td>3 (0.5)</td>
<td>3 (3.3)</td>
<td>6 (0.8)</td>
</tr>
<tr>
<td>Hemorrhagic shock</td>
<td>35 (4.8)</td>
<td>13 (2.0)</td>
<td>22 (24.4)</td>
</tr>
<tr>
<td>Blood transfusion</td>
<td>80 (11.0)</td>
<td>28 (4.4)</td>
<td>52 (57.8)</td>
</tr>
<tr>
<td>Mechanical ventilation</td>
<td>79 (10.9)</td>
<td>33 (5.2)</td>
<td>46 (51.1)</td>
</tr>
<tr>
<td>Surgery</td>
<td>107 (14.7)</td>
<td>56 (8.8)</td>
<td>51 (56.7)</td>
</tr>
<tr>
<td>ICU admission</td>
<td>89 (12.2)</td>
<td>40 (6.3)</td>
<td>49 (54.4)</td>
</tr>
<tr>
<td>ICU length of stay (day)</td>
<td>3 (1–5)</td>
<td>2 (1–3)</td>
<td>3 (2–8)</td>
</tr>
<tr>
<td>Hospital length of stay (day)</td>
<td>1 (1–1)</td>
<td>1 (1–1)</td>
<td>5 (2–13)</td>
</tr>
<tr>
<td>Mortality</td>
<td>42 (5.8)</td>
<td>12 (1.9)</td>
<td>30 (33.3)</td>
</tr>
</tbody>
</table>

Values are presented as median (interquartile range) or number (%).

In-hospital complications in patients with multiple trauma are common and associated with a significant burden on both patients and trauma centers. Tracing these complications is crucial to establish the best practices for their reduction. The present study explored the characteristics and outcomes of patients with multiple trauma to add to the growing knowledge of posttrauma complications. We found that almost 10% of hospitalized adult patients with multiple trauma experienced at least one complication; in-hospital complications were also associated with poor outcomes, and ISS was identified as an important factor associated with complications.

The 12.4% posttrauma complication rate among multiple trauma patients in the current study is consistent with previous re-
According to our data, in-hospital complications in multiple trauma patients are associated with increased lengths of hospital stay and ICU stay, which is consistent with previous reports [10,12, 23]. These observations could be attributed to the fact that salvage of severely injured patients with multiple trauma necessitates more extended hospitalization and ICU care, increasing complications and vice versa. We also observed a strong association between mortality and posttrauma complications; in other words, multiple trauma patients with complications are at increased risk of death. Although the cost of care was not evaluated in the current study, the increase in both hospital length of stay and mortality undoubtedly enhances resource utilization. A previous study focused on the cost associated with traumatic injury showed that patients with complications are likely to have three to five times higher costs than those without complications [13].

Our findings also showed that ISS was significantly associated with in-hospital complications in multiple trauma patients. In particular, we observed that the rate of complications increased by 17% for every 1-point increase in ISS. Accordingly, in higher ISS category groups, more patients experienced complications and also more frequently suffered from major and multiple complications. A severe injury following a traumatic event can have an extreme impact on physiological mechanisms, including the immunological, endocrinological, and acute stress responses. Moreover, these patients usually undergo multiple transfusions, numerous invasive procedures, surgeries, and extended hospital care, making them vulnerable to developing complications. To date, several studies have indicated the direct effect of ISS on the occurrence of infection [24], thromboembolic events [25], and acute kidney injury [26] following the trauma. Therefore, calculating ISS as an independent predictor of posttrauma complications is crucial for the management of patients with trauma, and scores should be recorded in patients’ charts.
In addition to complications, another important metric is the mortality rate of complicated multiple trauma patients. Failure to rescue patients with complications is an evolving factor that identifies the hospital's quality of care of patients with trauma [27]. The mortality rate of multiple trauma patients with complications in the present study was measured as 33.3%, which is higher than rates in similar previous reports [20,21]. Several factors influence mortality following complications; some are related to clinicians and care providers, while others are related to patients. A study from Japan showed that trauma patients in high-performing hospitals had lower rates of complications and failure to rescue than those in low-performing hospitals [20]. Another study indicated that clinician-attributable errors in diagnosing and managing trauma patients with complications are a major contributor to mortality [21]. Age, preexisting comorbidities, and insurance status are also patient-related factors identified to significantly affect the mortality of trauma patients with complications [28–31].

The nature of multiple trauma injuries demands a multidisciplinary approach and real-time decision-making. Improving the quality of care and minimizing errors can successfully reduce the rate of in-hospital complications and related deaths in patients with multiple trauma. A recent study from the United States assessed eight million patients with trauma and noted a significant drop in posttrauma complications over a decade [18]. Therefore, adhering to resuscitation and prophylaxis protocols, besides identifying patients at greater risk, could be a key component for reducing complications in multiple trauma patients.

There were some limitations in the current study. First, this study had a retrospective design, and the recorded complications' correctness and completeness depended on the responsible clinicians. There might also be some patients with multiple trauma treated during the study period that were not included. Second, we could not confirm the causal relationship between events due to uncertainty about the complications' onset date. Third, this study did not collect data on prophylaxis or treatment approaches. To reduce the posttrauma complications in multiple trauma patients, future studies could investigate interventions that might improve trauma centers’ quality of care.

Multiple trauma injuries are associated with a wide list of in-hospital complications. ISS was detected as a major factor associated with in-hospital complications, implying its importance when managing patients with trauma. Multiple trauma patients with more severe injuries should receive high-quality care and preventive services to avoid unwanted complications.

ETHICS STATEMENT

The study protocol was reviewed and approved by the Institutional Review Board of Shahid Beheshti University of Medical Sciences (No. IR.SBMU.MSP.REC.1400.814). The requirement for informed consent from individual patients was waived due to the retrospective nature of the study. The study adheres to the principles outlined in the Declaration of Helsinki.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

FUNDING

None.

AUTHOR CONTRIBUTIONS

Conceptualization: MY, SS; Data curation: SD, SS; Formal analysis: SD, MY, SS; Investigation: MY, HM, SS; Methodology: MY, MFR, MF, SS; Project administration: MY, SS; Resources: MFR, MF; Software: MY; Supervision: SS; Validation: SS; Visualization: SS; Writing—original draft: SD, SS; Writing—review & editing: all authors. All authors read and approved the final manuscript.

ORCID

Shayan Dasdar https://orcid.org/0000-0001-5761-5098
Mahmoud Yousefifard https://orcid.org/0000-0001-5181-4985
Mehri Farhang Ranjbar Not available
Mehdi Forouzanfar Not available
Hamid Mazloom Not available
Saeed Safari https://orcid.org/0000-0002-7407-1739

REFERENCES


18. Jakobsen RK, Bonde A, Sillesen M. Assessment of post-trauma complications in eight million trauma cases over a decade in the USA. Trauma Surg Acute Care Open 2021;6:e000667.


Factors affecting patients who attempted suicide in the emergency department due to the prolonged pandemic of COVID-19

Hyunji Kim¹, Areum Durey², Soo Kang², Won Kyung Lee³, Ji Hye Kim², Seung Baik Han², Yu Jin Lee²

¹Department of Emergency Medicine, Inha University Hospital, Incheon, Korea
²Department of Emergency Medicine, Inha University College of Medicine, Incheon, Korea
³Department of Prevention and Management, Inha University College of Medicine, Incheon, Korea

Objective This study examined the characteristics of patients who attempted suicide in the emergency department before and during the COVID-19 pandemic.

Methods We compared data from patients in the emergency department following suicide attempts between January 2018 and December 2021. The patients were categorized into two groups: “pre–COVID-19” and “during COVID-19” pandemic.

Results The findings revealed an increasing trend of suicide attempts during the study period. Suicide attempts were reported at 1,107 before the COVID-19 pandemic and 1,356 during the COVID-19 pandemic. Patients who attempted suicide during the COVID-19 pandemic were younger (38.0 ± 18.5 years vs. 40.7 ± 18.4 years, P < 0.01), had a smaller proportion of men (36% vs. 44%, P < 0.01), and had fewer medical comorbidities (20.2% vs. 23.6%, P < 0.05). The group during the COVID-19 pandemic reported better hygiene conditions (50.5% vs. 40.8%, P < 0.01) and lower alcohol consumption (27.7% vs. 37.6%, P < 0.01). Patients who attempted suicide during the COVID-19 pandemic had higher rates of use of psychiatric medications and previous suicide attempts. The most common reasons for the suicide attempt were unstable psychiatric disorders (38.8%), poor interpersonal relationships (20.5%), and economic difficulties (14.0%). Drug poisoning (44.1%) was the most common method of suicide attempts. Subgroup analysis with patients who attributed their suicide attempts to COVID-19 revealed a higher level of education (30.8%) and employment status (69.2%), with economic difficulties (61.6%) being the primary cause of suicide attempts.

Conclusion These findings suggest that the prolonged duration of the COVID-19 pandemic and its effects on social and economic factors have influenced suicide attempts.

Keywords Suicide; COVID-19; Economic factors
INTRODUCTION

The COVID-19 pandemic has directly and indirectly affected daily life worldwide. As an unprecedented infectious disease, it has strongly affected aspects of global health that have previously been taken for granted. Mask-wearing has become essential to prevent viral transmission, and most countries have begun social distancing, thus limiting social encounters. It is now natural to track movements using quick response (QR) codes and provide contact information to infected people. Remote office work and online classes for students in schools have become more common. Cultural and performance events with large crowds have largely disappeared, and the forms of essential gatherings, such as weddings and holiday events, have changed significantly.

As these changes in life persist, the "corona blue" phenomenon spreads. As daily life shifted to nonphysical interactions, social isolation was maximized, and the boundaries of each field collapsed, creating emotional instability [1]. Offline economic activity has declined sharply. High unemployment and those who have not adapted to the changes have been directly affected by decreased income, causing anxiety, fear, and depression [2].

Suicide attempts are an important social measure of mental health outcomes and can be associated with economic and cultural status. According to the 2022 Suicide Prevention White Paper released in 2022, the suicide attempt rate in Korea was 24.6 per 100,000 people in 2019, the highest among Organization for Economic Co-operation and Development (OECD) member countries, more than twice the average for OECD countries [3]. After the outbreak of COVID-19, the number of people complaining of depression increased to 20% of the total population due to quarantine measures, such as national lockdown and self-isolation. The symptoms associated with anxiety and depression during the pandemic are not unique to Korea [4].

According to data from the US Centers for Disease Prevention and Control (CDC), 41% of those surveyed said they had experienced pandemic-related psychological abnormalities and a high proportion of respondents (11%) considered suicide. A higher suicide attempt rate during the COVID-19 pandemic was also reported in Japan, according to a 2-year survey conducted between 2020 and 2021 [5].

A Korean database study that predicts and compares suicide attempt rates using a forecasting model reported that the overall number of suicide attempts did not increase; however, the number of suicide attempts by women and young people did [6]. Additionally, studies that focus on changes in mortality rate have analyzed rescue factors of suicide attempters before and during the COVID-19 pandemic [7]. However, studies determining the direct or indirect effects of COVID-19 on suicide attempts after the outbreak are lacking.

This study aimed to compare the characteristics of patients who attempted suicide in the emergency department (ED) before and during the COVID-19 pandemic to examine the factors that affected suicide attempts in the ED during the prolonged COVID-19 pandemic.

METHODS

Ethics statement

This study was approved by the Institutional Review Board of Inha University Hospital (No. 2021-05-023). The requirement for informed consent was waived due to the retrospective nature of the study.

Study design and setting

Inha University Hospital (Incheon, Korea) is a tertiary academic hospital and suicide crisis prevention center in Korea. We conducted a retrospective study using data obtained from medical records and counseling surveys conducted in the ED of our hospital. This ED-based suicide crisis prevention center started in 2017 and has a 24-hour operating system. This suicide crisis prevention center mainly focuses on the initial evaluation, follow-up management, and community connection of suicide attempts among those who visit the ED. Through this, various information, such as the characteristics and demographic information of suicide attempts and the motivation, location, and method of suicide attempts, were recorded and follow-up management was conducted.

Data collection and variables

Patients who had attempted suicide and were seen at the hospital through a regional emergency medical center between January 1, 2018 and December 31, 2021, were included. Among patients who visited the ED, those whose intentionality could not be confirmed due to cardiac arrest or decreased consciousness were excluded. Caregiver counseling was recorded when it was impossible to interview the patient. Medical records, including psychiatric consultation and counseling records, were reviewed retrospectively.

Main outcomes

From January 1, 2018 to December 31, 2021, the medical records of patients who visited the hospital due to suicide attempts and counseling on follow-up management projects for suicide attempts were reviewed retrospectively. Demographic data included age, sex, history of chronic diseases, education, medical insur-
Risk factors for suicide during the COVID-19 pandemic, hygiene, employment status, marital status, ED vital signs, consciousness, alcohol consumption, ED exit results, and duration of stay in the ED. Hygiene categories were collected based on psychiatric consultation records. The insurance status and history were collected by checking medical records. Medicare is a vulnerable group that receives state funding. Suicide-related data included psychiatric history, mental illness history, history of previous suicide attempts, reasons for the suicide attempt, and method of suicide attempt. This information was collected from ED records, mental health consultations, and medical charts.

Based on the first reported COVID-19 case in January 2020, patients who were seen in the hospital for suicide attempts from January 1, 2018 to December 31, 2019, were in the "pre–COVID-19 pandemic" group, and those seen from January 1, 2020 to December 31, 2021, were in the "COVID-19 pandemic" group. Additionally, a small group analysis was conducted among patients who reported that suicide attempts during the COVID-19 pandemic were related to COVID-19. Suicide attempts of patients and COVID-19 associations were included only when associations mentioned by patients were recorded in the ED, during hospitalization, or on the psychiatric chart through a review of medical records.

**Statistical analysis**
Categorical variables were presented as frequency and percentage, and continuous variables were presented as mean ± standard deviation. Comparisons between groups were made using the chi-square test for categorical variables and the t-test for continuous variables. All reported P-values were two-sided and statistical significance was set at P < 0.05. A multivariate logistic regression analysis was performed to determine the association between COVID-19 suicide attempts and economic difficulties. Multivariate logistic regression analysis adjusted according to age, sex, chronic medical history, education, insurance, employment status, and marital status was performed to calculate the adjusted odds ratio and 95% confidence interval (CI). Stata ver. 16 (Stata Corp) was used for all analyses.

**RESULTS**

During the study period, 260,662 patients visited our hospital's ED. Data from 2,463 patients who had attempted suicide were analyzed. Before the COVID-19 pandemic, 1,107 suicide attempts were reported and 1,356 suicide attempts were reported during the COVID-19 pandemic. An increasing trend was observed annually, with 524 cases in 2018, 583 in 2019, 627 in 2020, and 729 in 2021 (Fig. 1).

**Demographic characteristics**
The mean age was 39.2 ± 18.5 years, and 977 patients (39.7%) were male. During the COVID-19 pandemic, patients who attempted suicide and were evaluated in the ED had a younger age, a lower proportion of men, and fewer past history of diseases such as diabetes and high blood pressure. There were no significant differences in the degree of education, proportion of Medicare users, and employment between the two groups. Regarding hygiene during ED visits, many groups of patients who attempted suicide during the COVID-19 pandemic were in good condition and drank significantly less. There were also differences in marital status and ED results (Table 1).

![Fig. 1. The trend of suicidal patients visiting the emergency department. Q, quarter.](image-url)
Psychiatric characteristics

A total of 1,339 patients (54.4%) had a history of psychiatric illness and there were no significant differences between the two groups. The most common psychiatric history was a major depressive disorder. Overall, more than half of the patients who attempted suicide were taking psychiatric medications, and the group who attempted suicide during the COVID-19 pandemic showed more use of psychiatric medications (n = 721, 53.2%) and previous suicide attempts (n = 376, 27.7%) than before the COVID-19 pandemic (P < 0.05). The causes of suicide attempts common in the two groups were issues related to psychiatric disorders (n = 956, 38.8%), interpersonal relationships (n = 505, 20.5%), economic difficulties (n = 345, 14.0%), physical illness (n = 106, 4.3%), and other causes not listed (n = 551, 22.4%). The methods of suicide attempt were the following: drug poisoning (n = 1,086, 44.1%), carbon monoxide poisoning (n = 358, 14.5%), drowning (n = 45, 1.8%), hanging (n = 128, 5.2%), falling (n = 42, 1.7%). Suicidal ideation (n = 66, 2.7%), self-harm with cutting and stabbing (n = 447, 18.1%), and others (n = 291, 11.8%) were also reported (Table 2).
The average age of the patients who mentioned that COVID-19 was a cause of suicide was 42.3 ± 16.9 years, and 42 (40.4%) were male. The proportion of patients graduating from high school or higher was 30.8%, the proportion of patients with a good hygiene status was 61.5%, and the proportion of patients with employment was relatively high at 69.2%. The most common cause of suicide in this group was economic difficulties, with the highest rate at 63.5%. The situation worsened by COVID-19 was also found to be the highest in terms of economic difficulties, with 61.6% (Table 3). Among the patients who visited during the COVID-19 pandemic, those who responded that COVID-19 affected suicide showed a significant association with attempted suicide for economic reasons (adjusted odds ratio, 12.25; 95% CI, 7.66–19.59) (Table 4).

## DISCUSSION
This study analyzed more than 2,400 patients who attempted suicide. During the COVID-19 pandemic, the number of suicide attempts steadily increased. The most common cause of suicide was an existing psychiatric disorder, and the most common method of suicide attempt was drug poisoning. Patients who attempted suicide due to COVID-19 were driven primarily by economic reasons that caused the attempt.

We found an increase in the number of suicide attempts during the COVID-19 pandemic. The unexpected spread of COVID-19 and the rising distress in the community have led to a pandemic, which may eventually lead to an increasing trend in reported suicide attempts during the COVID-19 pandemic compared with similar pandemics worldwide. This is consistent with the results of previous studies [8,9]. A Japanese study [10] compared changes in suicide attempt rates by period and reported that there were no significant changes immediately after COVID-19; however, as the disaster situation increased, the suicide attempt rate peaked in the fall of 2020, followed by a downward trend.

According to the World Health Organization (WHO) [8], previous attempts at suicide in normal situations are considered the most important risk factor for suicide among the public. However, a recent systematic review [11] identified domestic conflict and violence, financial or job loss, anxiety, depression, and existing psychiatric conditions as risk factors. The study also found that groups that attempted suicide during the COVID-19 pandemic had higher rates of use of psychiatric medications and previous suicide attempts than those before the COVID-19 pandemic. This can be interpreted as being affected by risk factors for social iso-

### Table 2. Psychiatric and suicidal characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Total (n=2,463)</th>
<th>During COVID-19 (n=1,356)</th>
<th>Pre–COVID-19 (n=1,107)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Psychiatric medication</td>
<td>1,271 (51.6)</td>
<td>721 (53.2)</td>
<td>550 (49.7)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Psychiatric illness</td>
<td>1,339 (54.4)</td>
<td>753 (55.5)</td>
<td>586 (52.9)</td>
<td>0.28</td>
</tr>
<tr>
<td>Major depressive disorder</td>
<td>887 (36.0)</td>
<td>506 (37.3)</td>
<td>381 (34.4)</td>
<td></td>
</tr>
<tr>
<td>Bipolar disorder</td>
<td>53 (2.2)</td>
<td>28 (2.1)</td>
<td>25 (2.3)</td>
<td></td>
</tr>
<tr>
<td>Schizophrenia or psychotic disorder</td>
<td>51 (2.1)</td>
<td>30 (2.2)</td>
<td>21 (1.9)</td>
<td></td>
</tr>
<tr>
<td>Anxiety disorder or panic disorder</td>
<td>69 (2.8)</td>
<td>38 (2.8)</td>
<td>31 (2.8)</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>279 (11.3)</td>
<td>151 (11.1)</td>
<td>128 (11.6)</td>
<td></td>
</tr>
<tr>
<td>Previous suicide attempt</td>
<td>592 (24.0)</td>
<td>376 (27.7)</td>
<td>216 (19.5)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Motivation of suicide attempt</td>
<td></td>
<td></td>
<td></td>
<td>0.17</td>
</tr>
<tr>
<td>Psychiatric disorder</td>
<td>956 (38.8)</td>
<td>515 (38.0)</td>
<td>441 (39.8)</td>
<td></td>
</tr>
<tr>
<td>Interpersonal relationship</td>
<td>505 (20.5)</td>
<td>279 (20.6)</td>
<td>226 (20.4)</td>
<td></td>
</tr>
<tr>
<td>Economic difficulty</td>
<td>345 (14.0)</td>
<td>211 (15.6)</td>
<td>134 (12.1)</td>
<td></td>
</tr>
<tr>
<td>Physical illness</td>
<td>106 (4.3)</td>
<td>57 (4.2)</td>
<td>49 (4.4)</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>551 (22.4)</td>
<td>294 (21.7)</td>
<td>257 (23.2)</td>
<td></td>
</tr>
<tr>
<td>Method of suicide attempt</td>
<td></td>
<td></td>
<td></td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Drug ingestion</td>
<td>1,086 (44.1)</td>
<td>583 (43.0)</td>
<td>503 (45.4)</td>
<td></td>
</tr>
<tr>
<td>Self-harm (cutting, stabbing)</td>
<td>447 (18.1)</td>
<td>277 (20.4)</td>
<td>170 (15.4)</td>
<td></td>
</tr>
<tr>
<td>Carbon monoxide poisoning</td>
<td>358 (14.5)</td>
<td>168 (12.4)</td>
<td>190 (17.2)</td>
<td></td>
</tr>
<tr>
<td>Hanging</td>
<td>128 (5.2)</td>
<td>68 (5.0)</td>
<td>60 (5.4)</td>
<td></td>
</tr>
<tr>
<td>Suicidal ideation only</td>
<td>66 (2.7)</td>
<td>46 (3.4)</td>
<td>20 (1.8)</td>
<td></td>
</tr>
<tr>
<td>Drowning</td>
<td>45 (1.8)</td>
<td>22 (1.6)</td>
<td>23 (2.1)</td>
<td></td>
</tr>
<tr>
<td>Fall down</td>
<td>42 (1.7)</td>
<td>25 (1.8)</td>
<td>17 (1.5)</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>291 (11.8)</td>
<td>167 (12.3)</td>
<td>124 (11.2)</td>
<td></td>
</tr>
</tbody>
</table>

Values are presented as number (%). Percentages may not total 100 due to rounding.
The increase in employment instability and the decrease in income due to the prolonged COVID-19 pandemic have negatively affected mental health. The economy has stagnated due to limited social and economic activity worldwide, and many people are experiencing a decrease in income and job insecurity [12–14]. Reduced employment during the COVID-19 pandemic reduces psychological well-being and increases depression [15]. In this study, the main cause of attempted suicide was mental disorders, followed by interpersonal relationships in all patients before and after the COVID-19 pandemic. More than 60% of the patients attempted suicide due to the influence of COVID-19. The prolonged COVID-19 pandemic is not expected to adversely affect mental health; however, it is important to specifically confirm which patients who attempted suicide were adversely affected to attempt suicide.

In this study, there was an increase in suicide attempts among patients who were single (47.5% vs. 41.3%) and divorced (12.0% vs. 10.5%) during the pandemic, showing that people without families may have suffered more severely due to the constraints of the pandemic. The increase in employment instability and the decrease in income due to the prolonged COVID-19 pandemic have negatively affected mental health. The economy has stagnated due to limited social and economic activity worldwide, and many people are experiencing a decrease in income and job insecurity [12–14]. Reduced employment during the COVID-19 pandemic reduces psychological well-being and increases depression [15]. In this study, the main cause of attempted suicide was mental disorders, followed by interpersonal relationships in all patients before and after the COVID-19 pandemic. More than 60% of the patients attempted suicide due to the influence of COVID-19. The prolonged COVID-19 pandemic is not expected to adversely affect mental health; however, it is important to specifically confirm which patients who attempted suicide were adversely affected to attempt suicide.

In this study, there was an increase in suicide attempts among patients who were single (47.5% vs. 41.3%) and divorced (12.0% vs. 10.5%) during the pandemic, showing that people without families may have suffered more severely due to the constraints of the pandemic. A previous study reported an increase in the risk of suicide in people living alone or in metropolitan areas during the pandemic, and another study reported an increase in the suicide rate of socially vulnerable people, such as women, people

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value (n = 104)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>42.3 ± 16.9</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>42 (40.4)</td>
</tr>
<tr>
<td>Female</td>
<td>62 (59.6)</td>
</tr>
<tr>
<td>Chronic medical history</td>
<td>21 (20.2)</td>
</tr>
<tr>
<td>Education status (high school graduate)</td>
<td>32 (30.8)</td>
</tr>
<tr>
<td>Medicare</td>
<td>12 (11.5)</td>
</tr>
<tr>
<td>Hygiene status</td>
<td></td>
</tr>
<tr>
<td>Good</td>
<td>64 (61.5)</td>
</tr>
<tr>
<td>Not bad</td>
<td>6 (6.8)</td>
</tr>
<tr>
<td>Bad</td>
<td>19 (18.3)</td>
</tr>
<tr>
<td>Unknown</td>
<td>15 (14.4)</td>
</tr>
<tr>
<td>Employed</td>
<td>72 (69.2)</td>
</tr>
<tr>
<td>Marital status</td>
<td></td>
</tr>
<tr>
<td>Married</td>
<td>33 (31.7)</td>
</tr>
<tr>
<td>Single</td>
<td>42 (40.4)</td>
</tr>
<tr>
<td>Divorced</td>
<td>27 (26.0)</td>
</tr>
<tr>
<td>Unknown</td>
<td>2 (1.9)</td>
</tr>
<tr>
<td>Mental status</td>
<td></td>
</tr>
<tr>
<td>Alert</td>
<td>75 (72.1)</td>
</tr>
<tr>
<td>Drowsy</td>
<td>21 (20.2)</td>
</tr>
<tr>
<td>Stupor</td>
<td>8 (7.7)</td>
</tr>
<tr>
<td>Coma</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Alcohol ingestion</td>
<td>34 (32.7)</td>
</tr>
<tr>
<td>Emergency department disposition</td>
<td></td>
</tr>
<tr>
<td>Discharge</td>
<td>57 (54.8)</td>
</tr>
<tr>
<td>Admission</td>
<td></td>
</tr>
<tr>
<td>General ward admission</td>
<td>31 (29.8)</td>
</tr>
<tr>
<td>Intensive care unit admission</td>
<td>12 (11.5)</td>
</tr>
<tr>
<td>Psychiatric admission</td>
<td>2 (1.9)</td>
</tr>
<tr>
<td>Transfer to other hospital</td>
<td>2 (1.9)</td>
</tr>
<tr>
<td>Death</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Emergency department length of stay (min)</td>
<td>353.2±322.9</td>
</tr>
<tr>
<td>Psychiatric medication</td>
<td>51 (49.0)</td>
</tr>
<tr>
<td>Psychiatric illness</td>
<td>52 (50.0)</td>
</tr>
<tr>
<td>Major depressive disorder</td>
<td>41 (39.4)</td>
</tr>
<tr>
<td>Anxiety disorder or panic disorder</td>
<td>4 (3.9)</td>
</tr>
<tr>
<td>Bipolar disorder</td>
<td>1 (1.0)</td>
</tr>
<tr>
<td>Schizophrenia or psychotic disorder</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Other</td>
<td>6 (5.8)</td>
</tr>
<tr>
<td>Previous suicide attempt</td>
<td>24 (23.1)</td>
</tr>
<tr>
<td>Motivation of suicide attempt</td>
<td></td>
</tr>
<tr>
<td>Psychiatric disorder</td>
<td>21 (20.2)</td>
</tr>
<tr>
<td>Interpersonal relationship</td>
<td>14 (13.5)</td>
</tr>
<tr>
<td>Economic difficulty</td>
<td>66 (63.5)</td>
</tr>
<tr>
<td>Physical illness</td>
<td>3 (2.9)</td>
</tr>
<tr>
<td>Other</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Method of suicide attempt</td>
<td></td>
</tr>
<tr>
<td>Drug ingestion</td>
<td>45 (43.3)</td>
</tr>
<tr>
<td>Carbon monoxide poisoning</td>
<td>20 (19.2)</td>
</tr>
<tr>
<td>Self-harm (cutting, stabbing)</td>
<td>20 (19.2)</td>
</tr>
<tr>
<td>Drowning</td>
<td>6 (5.8)</td>
</tr>
</tbody>
</table>

Table 3. Subgroup analysis of patients who said COVID-19 affected suicide

Table 3. (Continued)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value (n = 104)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall down</td>
<td>3 (2.9)</td>
</tr>
<tr>
<td>Suicidal ideation</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Other</td>
<td>10 (9.6)</td>
</tr>
<tr>
<td>Worse due to COVID-19</td>
<td></td>
</tr>
<tr>
<td>Psychiatric disorder</td>
<td>27 (26.0)</td>
</tr>
<tr>
<td>Interpersonal relationship</td>
<td>6 (5.8)</td>
</tr>
<tr>
<td>Economic difficulty</td>
<td>64 (61.6)</td>
</tr>
<tr>
<td>Physical illness</td>
<td>2 (1.9)</td>
</tr>
<tr>
<td>Other</td>
<td>5 (4.8)</td>
</tr>
</tbody>
</table>

Values are presented as number (%). Percentages may not total 100 due to rounding.

Table 4. Multivariate logistic regression on COVID-19’s relevance to suicide attempts due to economic difficulties during the COVID-19 pandemic (n=1,356)

<table>
<thead>
<tr>
<th>Factor</th>
<th>Unadjusted analysis</th>
<th>Adjusted analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Influence of COVID-19</td>
<td>13.26</td>
<td>12.25</td>
</tr>
<tr>
<td>95% CI</td>
<td>8.58–20.49</td>
<td>7.66–19.59</td>
</tr>
</tbody>
</table>
| Adjusted for age, sex, chronic medical history, education, insurance, employed status, and marital status.

CI, confidence interval.
living alone, and minorities [16,17]. Studies have shown that continuous case management suicide crisis prevention centers for suicide reduce suicide reattempts. This is why more active and continuous case management for the vulnerable is needed in the future [18,19].

There are some limitations to this study. First, patients who were seen in the ED primarily for suicide attempts were targeted; if their intention was unknown, they were excluded from the study. Patients who repeatedly visited the hospital were included in the analysis. Generalization is limited because this was a cross-sectional study conducted at a single institution. However, it has the advantage of conducting an in-depth review of the relevance of COVID-19. Second, since this study was a retrospective review study of medical records, information was limited when the patient was in a coma or could not be obtained from a caregiver. Third, if the injury caused by suicide attempts is minor, it can be underestimated compared to before the COVID-19 pandemic. During the COVID–19 pandemic, medical resources have been concentrated in patients with more severe symptoms due to a lack of medical resources. In the case of tertiary academic hospitals such as this research institute, those who attempted suicide with mild symptoms may have had more difficulty accessing medical services. Fourth, in the small group analysis, the association between the patient’s suicide attempt and COVID-19 was limited to those affected only when the patient’s mentioned that COVID-19 was the reason for the suicide attempts was confirmed on the chart. Therefore, there was a limit for unidentified patients.

In conclusion, during the COVID–19 pandemic, the most common cause of suicide was an existing psychiatric disorder, and the most common method of suicide attempt was drug poisoning. Patients who attempted suicide due to COVID–19 were driven by economic reasons. These findings suggest that the prolonged duration of the pandemic and its effects on social and economic factors influence suicide attempts.

**ETHICS STATEMENT**

This study was approved by the Institutional Review Board of Inha University Hospital (No. 2021-05-023). The requirement for informed consent was waived due to the retrospective nature of the study.

**CONFLICT OF INTEREST**

No potential conflict of interest relevant to this article was reported.

**FUNDING**

This study was supported by the Inha University Research Grant (No. 64608-1, 2021).

**AUTHOR CONTRIBUTIONS**

Conceptualization: YJL, JHK; Data curation: HK, YJL, AD; Formal analysis: YJL, SK, WKL; Funding acquisition: YJL, SBH; Investigation: YJL, JHK; Methodology: YJL, WKL; Project administration: YJL, SBH; Resources: YJL, JHK; Software: YJL, SK; Supervision: YJL, SBH; Validation: YJL, SK, JHK; Visualization: YJL, SK, WKL; Writing–original draft: HK, YJL; Writing–review & editing: all authors. All authors read and approved the final manuscript.

**ORCID**

Hyunji Kim https://orcid.org/0009-0003-4560-9610
Areum Durey https://orcid.org/0000-0002-9353-6618
Soo Kang https://orcid.org/0000-0003-0800-1350
Won Kyung Lee https://orcid.org/0000-0002-6014-8854
Ji Hye Kim https://orcid.org/0000-0002-3262-1392
Seung Baik Han https://orcid.org/0000-0003-2660-7786
Yu Jin Lee https://orcid.org/0000-0002-6301-1175

**REFERENCES**

Relationships between trauma death, disability, and geographic factors: a systematic review

Bona Hwang¹, Taewook Jeong², Jiyeon Jo³,⁴

¹Korea Disease Control and Prevention Agency, Cheongju, Korea
²Department of Emergency Medical Technology, Seojeong University, Yanju, Korea
³Chungcheongbukdo Public Health Policy Institute, Cheongju, Korea
⁴Korea Paramedic Education Research Society, Seoul, Korea

Objective Trauma is a global health problem. The causes of trauma-related deaths are diverse and may depend in part on socioeconomic and geographical factors; however, there have been few studies addressing such relationships. The aim of this study was to investigate the relationships between trauma and geographical factors in order to support policy recommendations to reduce trauma-related deaths and disability.

Methods In accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, we searched international and Korean databases to retrieve relevant literature published between 2000 and 2020.

Results Thirty-two studies showed a positive relationship between the outcomes of major trauma and geographical factors. The study investigated regional factors including economic factors such as size of urban areas, gross domestic product, and poverty rate, as well as hospital parameters, such as presence of trauma centers and number of hospital beds. There was a tendency toward higher mortality rates in rural and low-income areas, and most of the studies reported that the presence of trauma centers reduced trauma-related mortality rates.

Conclusion Our study showed that geographic factors influence trauma outcomes. The findings suggest geographical considerations be included in care plans to reduce death and disability caused by trauma.

Keywords Wounds and injuries; Death; Disability; Geographical; Sociodemographic

What is already known

In the past, trauma was thought to impact low-income people to a greater degree because of poor medical access. The outcomes of trauma are influenced by various factors such as age, mechanism, surrounding environment, and other factors.

What is new in the current study

This study, through a systematic literature review, show that the factors affecting trauma treatment outcomes are not only individual, but also socioeconomic status, population density of residence area, surrounding environment, and other factors.
INTRODUCTION

Trauma is a global health problem [1], causing a reported 58 million global deaths every year, which represents about 10% of all deaths [2]. Since trauma was recognized as a critical cause of death and disability in patients, multiple studies of trauma-related mortality and disability have been published [3]. According to an annual report summarizing the causes of death published by Statistics Korea, 304,948 Koreans died from trauma in 2020. Among these, 26,442 (8.7%) died of external causes such as suicide, traffic accidents, and falls [4]. When expressed as incidence per 100,000 people, 25.7 died from suicide, 7.7 from traffic accidents, and 5.2 from falls. Worldwide, trauma is one of the leading causes of death, especially in the working age group (15 to 44 years), with many of the fatalities resulting from traffic accidents and self-harm. Socioeconomic losses due to trauma account for 60% to 62% of the total socioeconomic costs, indicating trauma to be associated with a high socioeconomic burden [5].

In the past, trauma was perceived to be a greater issue among low-income people with poor medical access. The US Department of Health and Human Service Centers for Disease Control and Prevention reported that deaths from trauma are not only a matter of concern in low-income counties, but also in high-income countries [6]. Today, it is believed that trauma can happen to anyone but is often preventable: as such, there are ongoing efforts to reduce trauma cases [1] that include measurement of preventable trauma death rates. Preventable traumatic deaths are defined as trauma-related deaths that would have been avoided if trauma patients had received clinically "correct" diagnoses and optimal medical care [7]. There is a large body of research related to preventable traumatic death rates in Korea [7–10], reporting rates of 40.5%, 39.6%, and 39.6% of trauma-related deaths in 1997–1998, 2003–2004, and 2009–2010, respectively. Researchers have predicted that if the medical infrastructure in Korea was equivalent to that of advanced nations, the preventable death rates would fall to less than 20% [8–11]. However, the preventable death rates may vary by region within a given country. Even if a country has well-established trauma care systems and improves medical quality at a national level, the quality and quantity of care may vary between regions, especially with respect to prehospital and in-hospital systems, medical resources, and level of medical centers [7,12]. The accessibility of medical services and service quality may significantly affect an individual's health [13].

The causes of trauma-related deaths may also vary regionally due to socioeconomic and geographical factors [3,14]. Many advanced nations have reported such a correlation between geographical factors and incidence of trauma [15,16]. There have been few Korean studies addressing the socioeconomic and geographical factors that influence trauma since most domestic studies have focused on trauma patterns, pattern analyses, and clinical outcomes related to trauma in certain body parts [17]. Based on the background above, the aim of the study was to investigate the relationships between trauma and geographical factors in order to support policies to reduce trauma-related deaths and disability. We performed a systematic review of published studies.

METHODS

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) guidelines were used for this study [18]. To ensure objectivity, two researchers independently reviewed the retrieved articles based on the PRISMA flowchart. The two researchers reached a consensus through discussions when they disagreed with the assessment. A risk-of-bias assessment was conducted for the articles included in the final set of references.

Reference literature

The research was conducted with literature published in Korean databases and several international databases from January 1, 2000 to December 31, 2020: RISS (Research Information Sharing Service), KISS (Korean Studies Information Service System), KBM-base (Korean Medical Database), KoreaMed, KNbase (Korean Nursing Database), National Assembly Library of Korea, PubMed, MEDLINE (via Ovid), Cochrane Library, ClinicalKey, CINAHL (Cumulative Index to Nursing and Allied Health Literature), and EBSCOhost, with the last date of search June 27, 2021.

Databases were selected based on systematic literature reviews. The search terms (both in Korean and English) were as follows: (1) “urbanization” AND “trauma” AND “outcome” OR “injury and wounds” AND “outcome” OR “trauma” AND “Glasgow Outcome Scale (GOS)” OR “injury and wound” AND “GOS” OR “injury and wound” AND “GOS” OR “injury and wounds” AND “outcome” OR “trauma” AND “GOS” OR “injury and wound” AND “GOS”; (2) “geographic” AND “trauma” AND “outcome” OR “injury and wounds” AND “outcome” OR “trauma” AND “GOS” AND “outcome” OR “injury and wounds” AND “outcome” OR “trauma” AND “GOS” AND “outcome” OR “injury and wounds” AND “GOS.”

Literature selection

The selection of publications for inclusion was conducted in two phases. In the first phase, the researchers reviewed the title and abstract of each of the initially selected articles and then excluded case studies and papers that did not consider geographic and sociodemographic factors. In the second phase, the articles se-
lected in the first phase were reassessed based on the following factors: (1) whether dependent variables were related to trauma patients; (2) whether geographic factors were considered independent variables and if the study clarified, what causes influenced the patient’s diagnosis of trauma; (3) whether the papers were published in an academic journal and analyzed correlations between trauma and regional factors; and (4) whether the papers met the purpose of this study.

Risk-of-bias assessment
A risk-of-bias assessment was conducted for the 32 studies selected for inclusion. The risk-of-bias assessment may also be called a quality assessment or critical appraisal of the included studies. The risk-of-bias assessment is needed to avoid any wrong conclusion due to heterogeneity, publication bias, etc. during a systematic literature review [19]. We used a checklist (QualSyst) developed by the Alberta Heritage Foundation for Medical Research to assess the risk of bias in the included quantitative studies. QualSyst is a verified systematic review tool and very practical and useful for various study designs [20,21]. The QualSyst checklist includes 14 items, but only 11 were used for this study [22].

RESULTS
Literature selection and risk-of-bias assessment
A total of 170,425 articles was searched, of which 81,264 were selected after excluding duplicate publications. After the first phase of selection, 141 articles remained. Of the 141 articles, 109 were excluded based on the criteria for the second phase of literature selection. The reasons for exclusion were as follows: (1) 12 articles dealt with dependent variables but were not related to trauma; (2) 86 articles did not consider geographical variables; (3) five articles did not assess the outcomes of trauma; and (4) six articles did not meet the purpose of this study. If an article failed for more than two reasons, the first factor we considered was whether the outcome was due to injury (in order of (1), (2) and (3)). Finally, we reviewed the remaining 32 articles published from January 1, 2010 to December 31, 2020 (Fig. 1).
We assessed risk of bias in the 32 studies based on the 11 items of the QualSyst checklist and scored them 0 (no), 1 (partial), 2 (moderate), 3 (high), and 4 (serious). The results are summarized in Table 1.
Table 1. QualSyst (Alberta Heritage Foundation for Medical Research) for quality assessment in the study (n=32)

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Are questions/objectives sufficiently described?</td>
<td>24 (75.0), 7 (21.9), 1 (3.1), 0 (0)</td>
</tr>
<tr>
<td>Is study design evident and appropriate?</td>
<td>11 (34.4), 14 (43.8), 7 (21.9), 0 (0)</td>
</tr>
<tr>
<td>Are methods of subject/comparison group selections or source of information/input variables described and appropriate?</td>
<td>22 (68.8), 9 (28.1), 1 (3.1), 0 (0)</td>
</tr>
<tr>
<td>Are subject (and comparison group, if applicable) characteristics sufficiently described?</td>
<td>18 (56.3), 9 (28.1), 3 (9.4), 2 (6.3)</td>
</tr>
<tr>
<td>Are the outcomes and (if applicable) exposed measure(s) well defined and robust to measurement/misclassification bias? Are means of the assessment reported?</td>
<td>17 (53.1), 10 (31.3), 5 (15.6), 0 (0)</td>
</tr>
<tr>
<td>Are sample sizes appropriate?</td>
<td>28 (87.5), 4 (12.5), 0 (0), 0 (0)</td>
</tr>
<tr>
<td>Are analytic methods described/justified appropriately?</td>
<td>23 (71.9), 9 (28.1), 0 (0), 0 (0)</td>
</tr>
<tr>
<td>Are some estimates of variables reported for the main results?</td>
<td>11 (34.4), 3 (8.4), 17 (53.1), 1 (3.1)</td>
</tr>
<tr>
<td>Are confound variables well-controlled?</td>
<td>17 (53.1), 6 (18.8), 8 (25.0), 1 (3.1)</td>
</tr>
<tr>
<td>Are results reported in detail?</td>
<td>24 (75.0), 7 (21.9), 1 (3.1), 0 (0)</td>
</tr>
<tr>
<td>Does the conclusion correspond to the result?</td>
<td>29 (90.6), 2 (6.3), 1 (3.1), 0 (0)</td>
</tr>
</tbody>
</table>

Table 2. General characteristics of cited studies

<table>
<thead>
<tr>
<th>Study</th>
<th>Category</th>
<th>Age (yr)</th>
<th>No. of subjects</th>
<th>Country</th>
<th>Database</th>
<th>Statistical analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moshiro et al. [27]</td>
<td>Individual</td>
<td>&gt; 15</td>
<td>15,223</td>
<td>Tanzania</td>
<td>Adult Morbidity and Mortality Project</td>
<td>Poisson regression</td>
</tr>
<tr>
<td>Fatovich et al. [29]</td>
<td>Individual</td>
<td>&gt; 15</td>
<td>3,333</td>
<td>Australia</td>
<td>Royal Flying Doctor Service and Trauma Registries</td>
<td>Logistic regression</td>
</tr>
<tr>
<td>Zandy et al. [30]</td>
<td>Individual</td>
<td>&gt; 15</td>
<td>10,445</td>
<td>Canada</td>
<td>British Columbia Mortality data</td>
<td>Logistic regression</td>
</tr>
<tr>
<td>Poulos et al. [33]</td>
<td>&lt; 15</td>
<td>Individual</td>
<td>2,981</td>
<td>New South Wales hospitals</td>
<td>Age-standardized mortality rates</td>
<td>Logistic regression</td>
</tr>
<tr>
<td>Dinh et al. [35]</td>
<td>&gt; 16</td>
<td>Individual</td>
<td>11,423</td>
<td>Australia</td>
<td>New South Wales Trauma Registry</td>
<td>Logistic regression</td>
</tr>
<tr>
<td>Wang et al. [36]</td>
<td>1–14</td>
<td>Individual</td>
<td>65,434</td>
<td>USA</td>
<td>California Office of Statewide Health Planning and Development Public Patient Discharge Database</td>
<td>Logistic regression</td>
</tr>
<tr>
<td>Iriarzy et al. [37]</td>
<td>Individual</td>
<td>&lt; 22</td>
<td>1,610</td>
<td>USA</td>
<td>South Florida trauma center</td>
<td>Logistic regression</td>
</tr>
<tr>
<td>Jarman et al. [40]</td>
<td>Individual</td>
<td>&gt; 18</td>
<td>8,673,213</td>
<td>USA</td>
<td>2009–2010 Nationwide Emergency Department Sample</td>
<td>Logistic regression</td>
</tr>
<tr>
<td>Jarman et al. [44]</td>
<td>Individual</td>
<td>&gt; 18</td>
<td>11,100,211</td>
<td>USA</td>
<td>2015 Maryland Adult Trauma Registry</td>
<td>Logistic regression</td>
</tr>
<tr>
<td>Wandling et al. [45]</td>
<td>Individual</td>
<td>&gt; 18</td>
<td>16,082</td>
<td>USA</td>
<td>Geographically weighted regression, logistic regression</td>
<td>Logistic regression</td>
</tr>
<tr>
<td>Bhutiani et al. [49]</td>
<td>Individual</td>
<td>17–25</td>
<td>615</td>
<td>USA</td>
<td>University of Louisville Trauma Registry</td>
<td>Logistic regression</td>
</tr>
<tr>
<td>Ciesla et al. [50]</td>
<td>Individual</td>
<td>&gt; 18</td>
<td>14,653</td>
<td>USA</td>
<td>2009 Florida Agency for Health Care Administration database</td>
<td>Logistic regression</td>
</tr>
<tr>
<td>Lee et al. [51]</td>
<td>Individual</td>
<td>&gt; 35</td>
<td>36,242</td>
<td>Korea</td>
<td>Statistics Korea (cause-of-death statistics, population and housing census)</td>
<td>Logistic regression model</td>
</tr>
<tr>
<td>Liu et al. [52]</td>
<td>Individual</td>
<td>&gt; 15</td>
<td>9,714</td>
<td>China</td>
<td>Disease Surveillance Point System</td>
<td>Chi-square test</td>
</tr>
<tr>
<td>Chen et al. [53]</td>
<td>Individual</td>
<td>17–25</td>
<td>644</td>
<td>Australia</td>
<td>New South Wales State records</td>
<td>Chi-square test</td>
</tr>
<tr>
<td>Brown et al. [16]</td>
<td>Region (state)</td>
<td>&gt; 15</td>
<td>48 States</td>
<td>USA</td>
<td>CDC</td>
<td>Logistic regression</td>
</tr>
<tr>
<td>Razzaghi et al. [39]</td>
<td>Region (city)</td>
<td>&gt; 15</td>
<td>31 Cities</td>
<td>Iran</td>
<td>Ministry of Health and Medical Education</td>
<td>Logistic regression</td>
</tr>
<tr>
<td>Brown et al. [41]</td>
<td>Region (state)</td>
<td>&gt; 15</td>
<td>50 States</td>
<td>USA</td>
<td>CDC</td>
<td>Logistic regression</td>
</tr>
<tr>
<td>Pu et al. [42]</td>
<td>Region (prefecture)</td>
<td>&gt; 15</td>
<td>161 Prefectures</td>
<td>China</td>
<td>Disease Surveillance Point System</td>
<td>Logistic regression</td>
</tr>
<tr>
<td>Minei et al. [24]</td>
<td>Individual and region</td>
<td>&gt; 15</td>
<td>5,857 (8 States)</td>
<td>USA</td>
<td>ROC Epistry-Trauma</td>
<td>Logistic regression</td>
</tr>
<tr>
<td>Young et al. [26]</td>
<td>Adults</td>
<td>&gt; 15</td>
<td>11,576 (9 States)</td>
<td>USA</td>
<td>Administrative records of a large insurance company</td>
<td>Logistic regression</td>
</tr>
<tr>
<td>Snyder et al. [28]</td>
<td>Individual and region</td>
<td>&lt; 15</td>
<td>34,816 (7 Provinces)</td>
<td>USA</td>
<td>Florida Agency for Health Care Administration</td>
<td>Logistic regression</td>
</tr>
<tr>
<td>Wolf et al. [31]</td>
<td>Individual and region</td>
<td>&lt; 15</td>
<td>18,116 (51 States)</td>
<td>USA</td>
<td>Fatality Analysis Reporting System</td>
<td>Logistic regression</td>
</tr>
</tbody>
</table>

(Continued on the next page)
Table 2. (Continued)

<table>
<thead>
<tr>
<th>Study</th>
<th>Age (yr)</th>
<th>Category</th>
<th>No. of subjects</th>
<th>Country</th>
<th>Database</th>
<th>Statistical analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kim et al. [34] (2011)</td>
<td>&gt; 18</td>
<td>Individual and region</td>
<td>21,868 (229 Cities, provinces, or districts)</td>
<td>Korea</td>
<td>Statistics Korea (cause-of-death statistics)</td>
<td>Poisson HGLM</td>
</tr>
<tr>
<td>Brown et al. [46] (2016)</td>
<td>&gt; 15</td>
<td>Individual and region</td>
<td>193,629 (Northeast and southwest regions)</td>
<td>USA</td>
<td>National Trauma Database</td>
<td>Logistic regression</td>
</tr>
<tr>
<td>Beaulieu et al. [47] (2020)</td>
<td>All</td>
<td>Individual and region</td>
<td>145,252 (4 Cities)</td>
<td>Canada</td>
<td>National Fire Information Database</td>
<td>Simple linear regression</td>
</tr>
<tr>
<td>Elkindi et al. [48] (2020)</td>
<td>All</td>
<td>Individual and region</td>
<td>317,500 (4 Regions)</td>
<td>USA</td>
<td>National Trauma Database</td>
<td>Chi-square test, t-test</td>
</tr>
<tr>
<td>Klop et al. [54] (2017)</td>
<td>&gt; 50</td>
<td>Individual and region</td>
<td>82,375 (10 Provinces)</td>
<td>UK</td>
<td>Clinical Practice Research Datalink</td>
<td>Poisson regression</td>
</tr>
<tr>
<td>Keeves et al. [25] (2019)</td>
<td>All</td>
<td>Individual and region</td>
<td>47 Articles</td>
<td>–</td>
<td>Articles</td>
<td>Scoping review</td>
</tr>
<tr>
<td>Newnam et al. [38] (2014)</td>
<td>&gt; 17</td>
<td>Other</td>
<td>96 Articles</td>
<td>–</td>
<td>Articles</td>
<td>Systematic review</td>
</tr>
</tbody>
</table>

GAM, generalized additive models; CDC, Centers for Disease Control and Prevention; WONDER, Wide-ranging Online Data for Epidemiologic Research; HGLM, hierarchical generalized linear models.

or 2 (yes). The two reviewers assessed the 32 studies and compared the results. When disagreements occurred, consensus was reached through discussions involving a third author (Table 1).

QualSyst recommends exclusion of articles that do not meet the minimum threshold of 0.55 from a systematic review [23]. Some articles did not meet some criteria, but they were also reviewed since the total score of each of them was more than 0.99 (Supplementary Table 1) [16,24–54].

Structure of the study

We found that 27 of the 32 studies (84.4%) [16,24,25,28–31,34,35,37–54] were published after 2010, indicating that geographic factors influencing major trauma have recently become a priority for study. Of the 32 studies, 18 studies [16,24,25,27,29,30,32,39–43,45,47–50,52] selected study subjects of all ages, eight studies [26,34,35,38,44,46,51,53] were adults, one [54] studied people in their 50s or older, and five [28,31,33,36,37] studied children and adolescents.

Data sources and methods of analysis

Table 2 summarizes the general characteristics of the 32 studies [16,24–54]. Of the 32 studies, one [26] used data obtained from insurance companies, while all other used representative regional and national data; specifically, nine [16,31,34,40–42,46,48,51] used national data and one [32] used cross-national data, and the remainder [24–30,33,35–39,43–45,47,49,50,52–54] used regional data. Of the 32 articles, there was one systematic review [38] and one scoping review [25]. Nineteen studies (63.3%) [16,24,26,28,30,31,36,37,40,41,43–50,52] used data from the United States, four studies (13.3%) [34,39,42,51] from Asia, three studies (10.0%) [29,33,53] from Oceania, three studies (10.0%) [32,35,54] from Europe, and one study (3.3%) [27] from Africa.

The studies were assigned to one of five categories for assessment: 16 [27,29,30,33,35–37,40,43–45,49–53] in individual, four [16,39,41,42] in regional, 10 [24,26,28,31,32,34,46–48,54] in individual and regional, one [38] in systematic review, and one [25] in scoping review. The sample population sizes ranged from 614 to 8,673,213 subjects. Among the 32 articles, 23 [24,26–31,33–37,40,43–48,50–52,54] analyzed more than 1,000 subjects.

While some of the 32 studies used more than one data analysis method, the main method in six studies [24,27,34,43,51,54] was Poisson regression, 10 [26,28,29,32,35,36,40,44,46,49] used logistic regression, three [48,52,53] used chi-square test, and five [16,41,42,45,50] used geospatial analytics. The remaining studies [25,30,31,33,37–39,47] used other methods such as multivariate or multiple regression.

Geographic factors as independent variables and use of dependent variables

To classify the papers, we conducted two rounds of categorization: one considering the possibility of multiple category duplication and another with the aim of avoiding duplication. To avoid duplication, three authors discussed and selected the important variables and classified them into the corresponding categories geographic factors as independent variables were divided into three categories. First, we classified the studies focusing on the connections between social structures and geographic factors as “socio-economic.” Second, we categorized the studies focusing on medical resources as “medical-resource-related.” Finally, we categorized the studies focusing on environments where trauma is likely to occur as “environmental.” The results of the analyses showed that, with the exception of systematic and scoping review articles,

...
five studies [30,37,39,44,51] were classified as socioeconomic, six [16,36,45,46,48,50] as medical-resource–related, and 19 [24,26–29,31–35,40–43,47,49,52–54] as environmental (Table 3).

In another round where we considered the possibility of duplication (Table 4) [16,24,26–37,39–54], we divided the socioeconomic category into three subcategories: geodemographic, economic, and individual. Five studies [24,39,41,47,49] analyzed geodemographic factors such as population density; seven [34,39,42,43,46,51,53] analyzed economic factors such as gross domestic product, resident tax, house income, type of insurance, middle-class household income, poverty rate, and unemployment rate; and 11 [16,30,33,36,37,44,45,49,51,53,54] analyzed individual factors such as race, level of education, and per capita income.

The medical-resource–related category was divided into two subcategories: prehospital and in-hospital. Six [24,32,35,44–46] addressed prehospital factors such as distance from the site to a trauma center, time from scene to medical institution, type of transfer vehicle, and the numbers of helicopters and helipads; while 12 [16,28,32,35,36,40,43–46,48,50] analyzed in-hospital factors such as presence of a trauma center, level of trauma center, and number of beds.

The environmental category was also divided into three subcategories: road environment, geospatial factors, and legal factors. Among the 27 studies, one [39] addressed road characteristics of speed limit, type of road, road conditions, and roadway congestion index; 14 [26,27,29,33–35,40–44,52–54] analyzed geospatial factors such as urbanization and area of the city, and one [31] addressed legal factors such as regulations on seat belts and safety seats, red-light and speed-camera policies, speed limits, and laws applicable to driving under the influence.

Outcomes of trauma
We found that six types of dependent variable (mortality, disability, severity, survival and discharge, death and impairment, and work disability) were used in the 32 studies included in the analyses. Among the 32 studies, 22 [16,25,28–31,34,35,37,39–45,48,49,51–54] identified incidences of death and survival rate as dependent variables.

Table 3. Category and details of independent variables of 30 studies

<table>
<thead>
<tr>
<th>Independent variable category</th>
<th>Detail of independent variable</th>
<th>Study(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Socioeconomic</td>
<td>Social deprivation, material deprivation, insurance, racial, ethnic, household income, residential, etc.</td>
<td>5 Studies [30,37,39,44,51]</td>
</tr>
<tr>
<td>Medical resource</td>
<td>Presence of trauma center, helicopter transport</td>
<td>6 Studies [16,36,45,46,48,50]</td>
</tr>
<tr>
<td>Environmental</td>
<td>Geographic regions, rural areas, red light camera legislation, population density, etc.</td>
<td>19 Studies [24,26–29,31–35,40–43,47,49,52–54]</td>
</tr>
</tbody>
</table>

*Two studies were systematic review [38] and scoping review [25].

Table 4. Detail of categorization for independent variables and their use of 30 studies

<table>
<thead>
<tr>
<th>Variable</th>
<th>Study(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Socioeconomic</td>
<td></td>
</tr>
<tr>
<td>Geodemographic</td>
<td>[16]</td>
</tr>
<tr>
<td>Economic</td>
<td>[24]</td>
</tr>
<tr>
<td>Individual</td>
<td>[26]</td>
</tr>
<tr>
<td>Medical resource</td>
<td>[39]</td>
</tr>
<tr>
<td>Prehospital</td>
<td></td>
</tr>
<tr>
<td>In-hospital</td>
<td></td>
</tr>
<tr>
<td>Environmental</td>
<td></td>
</tr>
<tr>
<td>Road environment</td>
<td>[40]</td>
</tr>
<tr>
<td>Geospatial</td>
<td></td>
</tr>
<tr>
<td>Legal</td>
<td>[41]</td>
</tr>
</tbody>
</table>

Excluding systematic review [38] and scoping review [25].

Table 5. Dependent variables and data source used for the 32 studies

<table>
<thead>
<tr>
<th>Type of dependent variable</th>
<th>Data source</th>
<th>Detail of dependent variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mortality</td>
<td>Medical records, Scoping review</td>
<td>Death or survival</td>
</tr>
<tr>
<td>Disability</td>
<td>Survey</td>
<td>Duration of disability</td>
</tr>
<tr>
<td>Severity</td>
<td>Medical records</td>
<td>Injury Severity Score &gt; 16</td>
</tr>
<tr>
<td>Survival and discharge</td>
<td>Medical records</td>
<td>Survival and discharge</td>
</tr>
<tr>
<td>Death and impairment</td>
<td>Medical records, Systematic review</td>
<td>Death and impairment (hospice)</td>
</tr>
<tr>
<td>Work disability</td>
<td>Administrative records, No. of absences</td>
<td></td>
</tr>
</tbody>
</table>

Outcomes of trauma
We found that six types of dependent variable (mortality, disability, severity, survival and discharge, death and impairment, and work disability) were used in the 32 studies included in the analyses. Among the 32 studies, 22 [16,25,28–31,34,35,37,39–45,48,49,51–54] identified incidences of death and survival rate as dependent variables.
Table 6. Geographical impact on the outcomes of trauma

<table>
<thead>
<tr>
<th>Study</th>
<th>Age</th>
<th>Comparison</th>
<th>Independent variable category</th>
<th>Explanation and details of outcome of articles</th>
<th>Representative outcome</th>
<th>Dependent variable category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moshiro et al. [27] (2005)</td>
<td>All ages</td>
<td>Urban vs. rural</td>
<td>Environmental</td>
<td>Lower impairment rates in urban areas during the recovery period***</td>
<td>OR, 2.60 (95% CI, 1.05 to 6.53)</td>
<td>Disability</td>
</tr>
<tr>
<td>Fatovich et al. [28] (2011)</td>
<td>All ages</td>
<td>Urban vs. rural</td>
<td>Environmental</td>
<td>Higher risk of death in rural areas*</td>
<td>OR, 2.60 (95% CI, 1.05 to 6.53)</td>
<td>Mortality</td>
</tr>
<tr>
<td>Zandy et al. [30] (2019)</td>
<td>All ages</td>
<td>Regions</td>
<td>Socioeconomic</td>
<td>Higher risk of death in low-income areas*</td>
<td>903.2 vs. 1839 Standardized mortality rate per 100,000 for death</td>
<td>Mortality</td>
</tr>
<tr>
<td>Gomez de Segura Neva et al. [32] (2009)</td>
<td>All ages</td>
<td>Nations (French vs. Spain)</td>
<td>Environmental</td>
<td>Multivariates including age, sex, severity of trauma were corrected and the result showed the mortality rate at Atlantic Pyrenees (France) was 79% higher than Navarra (Spain)</td>
<td>No significant differences in death mortality</td>
<td>Mortality</td>
</tr>
<tr>
<td>Brown et al. [16] (2016)</td>
<td>All ages</td>
<td>Regions</td>
<td>Medical resource</td>
<td>Fatality rate and nearest neighbor ratios were correlated*</td>
<td>56.9 (IQR, 46.5 to 58.9) vs. 64.9 (IQR, 52.5 to 77.1)</td>
<td>Mortality</td>
</tr>
<tr>
<td>Razzaghi et al. [39] (2019)</td>
<td>All ages</td>
<td>Urban vs. rural</td>
<td>Socioeconomic</td>
<td>A unit (1 million Iranian Rial) increase in the GDP of the province, the number of deaths decreased by as much as 0.0014** When the population density increases one unit, the number of people died in traffic accidents rises 30***</td>
<td>Range, 17.48 to 43.48</td>
<td>Mortality</td>
</tr>
<tr>
<td>Jarman et al. [40] (2016)</td>
<td>All ages</td>
<td>Urban vs. rural</td>
<td>Environmental</td>
<td>The probability of death in trauma was 14% higher in rural area*** Increased odds of death for rural residents were observed at level I (OR, 1.20), level II (OR, 1.34), and level IV and nontrauma centers [OR, 1.23] ***</td>
<td>OR, 1.34 (95% CI, 1.16 to 1.54)</td>
<td>Mortality</td>
</tr>
<tr>
<td>Brown et al. [41] (2019)</td>
<td>All ages</td>
<td>Metropolitan vs. nonmetropolitan</td>
<td>Environmental</td>
<td>Among unintentional injuries, the head-injury death rate is 23% higher in rural areas than in urban areas, the injury by violence is 16% higher***</td>
<td>12.78 vs. 9.81 in fatality rate per 100,000</td>
<td>Mortality</td>
</tr>
<tr>
<td>Pu et al. [42] (2020)</td>
<td>All ages</td>
<td>Regions</td>
<td>Environmental</td>
<td>As environmental urbanization rate increased, 7.3 increase in the mortality rate of traffic accident**</td>
<td>t, –2.970766</td>
<td>Mortality</td>
</tr>
<tr>
<td>Jarman et al. [43] (2019)</td>
<td>All ages</td>
<td>Regions (by scale)</td>
<td>Environmental</td>
<td>Small cities and rural areas had higher prehospital trauma mortality rates than large cities***</td>
<td>IRR, 1.14 (95% CI, 1.05 to 1.23)</td>
<td>Mortality</td>
</tr>
<tr>
<td>Jarman et al. [44] (2018)</td>
<td>Adult</td>
<td>Regions (by income)</td>
<td>Socioeconomic</td>
<td>The trauma mortality rate in low-income cities is higher than other ***</td>
<td>OR, 1.98 (95% CI, 1.56 to 2.51)</td>
<td>Mortality</td>
</tr>
<tr>
<td>Brown et al. [46] (2016)</td>
<td>Adult</td>
<td>Regions (east, west, Medical resource south, north)</td>
<td>Environmental</td>
<td>HT was associated with an increased odds of in-hospital survival (survival and discharge rates were 1.5 and 1.2 times higher, respectively when patients are transferred by helicopterson)*** The survival rate was higher in the southern area than other areas*** Severity of injury, helicopter, and trauma centers, accessibility to trauma centers, and traffic congestion affected the transferability of helicopters*</td>
<td>AOR, 1.48 (95% CI, 1.44 to 1.52) OR, 1.29 (95% CI, 1.18 to 1.41)</td>
<td>Mortality</td>
</tr>
<tr>
<td>Beaulieu et al. [47] (2020)</td>
<td>All ages</td>
<td>Regions</td>
<td>Environmental</td>
<td>The death rate per 1,000 residential fire incidents was higher in suburban areas than urban areas</td>
<td>NA</td>
<td>Mortality</td>
</tr>
<tr>
<td>Elkbali et al. [48] (2020)</td>
<td>All ages</td>
<td>Regions (east, west, Medical resource south, north)</td>
<td>Environmental</td>
<td>Even controlled each level I to III trauma centers, there was difference mortality rate in each among areas</td>
<td>NA</td>
<td>Mortality</td>
</tr>
<tr>
<td>Bhutiani et al. [49] (2018)</td>
<td>All ages</td>
<td>Metropolitan vs. nonmetropolitan</td>
<td>Environmental</td>
<td>Pedestrian accidents were concentrated in cities* Higher median household income*** and higher population density* were associated with decreased likelihood of death following pedestrian vs. motor vehicle accident OR, 0.67 (95% CI, 0.52 to 0.86) OR, 0.97 (95% CI, 0.94 to 0.99)</td>
<td>NA</td>
<td>Mortality</td>
</tr>
<tr>
<td>Cesla et al. [50] (2012)</td>
<td>All ages</td>
<td>Hospitals</td>
<td>Medical resource</td>
<td>Even through 93% of patients live in areas where trauma centers are located, the treatment rate vary by regions from 13% to 58% and the rate is relatively low Trauma centers discharged 52% of major trauma patients</td>
<td>NA</td>
<td>Severely injured patients discharged</td>
</tr>
<tr>
<td>Study</td>
<td>Age</td>
<td>Comparison</td>
<td>Independent variable category</td>
<td>Explanation and details of outcome of articles</td>
<td>Representative outcome</td>
<td>Dependent variable category</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>-------------------</td>
<td>---------------------------</td>
<td>--------------------------------</td>
<td>----------------------------------------------------------------------------------------------------------------</td>
<td>------------------------</td>
<td>-----------------------------</td>
</tr>
<tr>
<td>Liu et al. [52] (2012)</td>
<td>All ages</td>
<td>Urban vs. rural</td>
<td>Environmental</td>
<td>The trauma mortality rate was 2.4 higher in rural areas than urban areas**</td>
<td>CRR, 1.9 (95% CI, 1.8 to 2.0)</td>
<td>Mortality</td>
</tr>
<tr>
<td>Wandling et al. [45] (2016)</td>
<td>All ages</td>
<td>Regions</td>
<td>Medical resource</td>
<td>It takes more than 30 min to transfer gunshot wounds adult patients to trauma centers from the south of Chicago (pediatric trauma centers are in the southeast)</td>
<td>NA</td>
<td>Mortality</td>
</tr>
<tr>
<td>Minei et al. [24] (2010)</td>
<td>All ages</td>
<td>Regions</td>
<td>Environmental</td>
<td>There were regional differences in measures related to injury, such as incidence and survival rate*</td>
<td>NA</td>
<td>Survival ranged</td>
</tr>
<tr>
<td>Keeves et al. [25] (2019)</td>
<td>All ages</td>
<td>Urban vs. rural</td>
<td>Environmental</td>
<td>Both the hospital and prehospital mortality rates are higher in rural areas</td>
<td>Scoping review</td>
<td>Mortality</td>
</tr>
<tr>
<td>Young et al. [26] (2008)</td>
<td>Adults</td>
<td>Urban vs. rural</td>
<td>Environmental</td>
<td>The work disability rate was higher in urban areas than rural areas***</td>
<td>OR, 0.78 (95% CI, 0.72 to 0.84)</td>
<td>Disability</td>
</tr>
<tr>
<td>Kim et al. [34] (2011)</td>
<td>Adults</td>
<td>Regions</td>
<td>Environmental</td>
<td>Lower mortality from transport accidents and suicides in high residence tax per person areas***</td>
<td>β, –0.141 (95% CI, –0.220 to –0.062)</td>
<td>Mortality</td>
</tr>
<tr>
<td>Dinh et al. [35] (2016)</td>
<td>Adults</td>
<td>Urban vs. rural</td>
<td>Environmental</td>
<td>Inpatient mortality for those injured in metropolitan locations was 14.7% in 2009 and 16.1% in 2014*</td>
<td>OR, 0.78 (95% CI, 0.72 to 0.84)</td>
<td>Disability</td>
</tr>
<tr>
<td>Lee et al. [51] (2014)</td>
<td>Adults</td>
<td>Regions</td>
<td>Socioeconomic</td>
<td>In areas where the poverty index is the lowest, traffic accidents, falling down, and suicide are 1.3**, 1.6***, and 1.1* times higher, respectively</td>
<td>RR, 1.34 (1.05 to 1.73); RR, 1.63 (1.20 to 2.20)</td>
<td>Mortality</td>
</tr>
<tr>
<td>Chen et al. [53] (2010)</td>
<td>Adults</td>
<td>Urban vs. rural</td>
<td>Environmental</td>
<td>Traffic accident fatality rates in cities decrease by 5% every year</td>
<td>χ², 11995</td>
<td>Mortality</td>
</tr>
<tr>
<td>Newnam et al. [38] (2014)</td>
<td>Adults</td>
<td>–</td>
<td>–</td>
<td>To seek the impact of injury to individual, community, societal level</td>
<td>Systematic review</td>
<td>Injury</td>
</tr>
<tr>
<td>Snyder et al. [28] (2017)</td>
<td>Children</td>
<td>Regions</td>
<td>Environmental</td>
<td>The mortality rate varies from region to region*</td>
<td>OR, 2.0 (95% CI, 1.6 to 2.6)</td>
<td>Mortality</td>
</tr>
<tr>
<td>Wolf et al. [31] (2017)</td>
<td>Children</td>
<td>Regions</td>
<td>Environmental</td>
<td>The treatment rate outside a region is different</td>
<td>χ², 0.05</td>
<td>Mortality</td>
</tr>
<tr>
<td>Poulos et al. [33] (2009)</td>
<td>Children</td>
<td>Regions</td>
<td>Environmental</td>
<td>Children in rural areas are at a higher risk of burn injury than their counterparts in urban areas*</td>
<td>RR &gt; 1.2, PP &gt; 0.8 (using Bayesian methods)</td>
<td>Morbidity</td>
</tr>
<tr>
<td>Wang et al. [36] (2008)</td>
<td>Children</td>
<td>Existence of trauma center</td>
<td>Medical resource</td>
<td>Higher accessibility of children with moderate or major trauma to trauma centers***</td>
<td>OR, 3.95 (95% CI, 3.43 to 4.54)</td>
<td>Hospitalized</td>
</tr>
<tr>
<td>Inzarry et al. [37] (2017)</td>
<td>Children</td>
<td>Regions</td>
<td>Socioeconomic</td>
<td>African American children have a higher GSW risk and mortality rate and most of the GSW cases for African American children occur in areas where they live**</td>
<td>Hispanic children: RR, 0.37 (95% CI, 1.18 to 0.79); White children: RR, 0.08 (95% CI, 0.04 to 0.16)</td>
<td>Prevalence, mortality</td>
</tr>
<tr>
<td>Klopf et al. [54] (2017)</td>
<td>Middle-aged to elderly</td>
<td>Regions</td>
<td>Environmental</td>
<td>Most cities, other than London, show higher mortality rates of fracture among women*</td>
<td>RR, 1.37 (95% CI, 1.18 to 1.58)</td>
<td>Mortality</td>
</tr>
</tbody>
</table>

OR, odds ratio; CI, confidence interval; IQR, interquartile range; GDP, gross domestic product; IRR, incidence rate ratios; AOR, adjusted odds ratio; NA, not available; CRR, crude rate ratio; RR, relative risk; PP, posterior probability; GSW, gunshot wound.

*P < 0.05, **P < 0.01, ***P < 0.001. 'No significance.
pended variables, and the rest used disability rate [27], death and impairment rate [28,38,47], severity of trauma [32,36], survival and discharge rates [24,33,46,50], and work disability rates [26]. Dependent variables were identified through medical records in 28 studies (91%) [16,24,28–37,39–54], through a survey in one study (3%) [27], through a large insurance company in one study (3%) [26], and the remaining two studies were a systematic literature review [38] and a scoping review [25].

More specifically, Wang et al. [36] referred to medical records to obtain trauma severity scores. Brown et al. [46] analyzed survival and discharge rates obtained from medical records. Moshiro et al. [27] used duration of impairment as reported through a survey. Young et al. [26] identified work disability through insurance records. Finally, Newnam et al. [38] conducted a systematic review for analyzing death and impairment. The above findings indicate that medical records are being widely used to assess the causes of major trauma (Table 5).

Correlations between outcomes of major trauma and geographic factors

We investigated the correlations between the outcomes and geographic factors and divided the subjects into four groups: all ages, adults, children, and middle-aged to elderly (Table 6). After excluding systematic and scoping review articles, the remaining 30 studies [16,24,26–37,39–54] showed a positive relationship between the outcomes of major trauma and geographic factors. The 19 studies [24,26–29,31–35,40–43,47,49,52–54] analyzing environmental factors also showed such positive relationships, as did five studies [30,37,39,44,51] analyzing socioeconomic factors and six studies [16,36,45,46,48,50] assessing medical resource factors.

Among the studies that examined factors affecting all age groups, environmental factors (12 studies [24,25,27,29,32,40–43,47,49,52]), socioeconomic factors (two studies [30,39]), and medical resources (four studies [16,45,48,50]) were the main variables identified. Studies that compared trauma outcomes in rural or urban environments showed that rural areas had higher mortality rates than urban areas, and studies that compared regional economic status found that low-income regions had higher mortality rates than high-income regions [29,39,51]. Bhutiani et al. [49] reported that traffic fatality rates increased as population density decreased.

With regard to medical resource factors, the better was accessibility to trauma centers, the lower were the death rates. Both death and disability rates are lower if patients can be transferred to hospitals with helicopters.

Five studies [26,34,35,51,53] focused on geographic factors affecting adult major trauma. Of these, four [26,34,35,53] addressed environmental factors, while one [51] addressed socioeconomic factors. In the four articles, three [26,34,53] showed higher mortality rates in rural area than in urban ones but an opposite result in impairment rate, with Dinh et al. [35] reporting opposite result regarding death. The articles analyzing socioeconomic factors showed higher incidence rates of trauma in low-income regions.

Among the five studies focusing on geographic factors influencing pediatric trauma, three [28,31,33] analyzed environmental factors, one [37] analyzed socioeconomic factors, and one [36] analyzed medical resource factors. The three articles assessing environmental factors showed that the risk of pediatric trauma was greater in rural areas and mortality was greater in regions where safety regulations were not established. One article [54] analyzed the outcomes of major geriatric trauma and showed that the female mortality rate increased in all regions except the capital.

Although the findings of the 32 studies [16,24–54] varied depending on factors such as region, accessibility to trauma centers, injury severity, and traffic congestion, they generally indicated that trauma outcomes differed according to the characteristic of the area in which the patients lived. For example, pedestrian fatality rates tended to be lower in high-income areas [49]. Also, trauma death rates were greater in low-income areas than other areas [44,49]. Additionally, the mortality rates for injuries and head trauma were greater in rural areas than in urban areas, and prehospital trauma mortality was higher in both urban and rural areas than in metropolises [25,41,43].

DISCUSSION

This study used a systematic literature review to retrieve articles published in Korea and foreign countries that analyzed the correlations between disability or death in major trauma and geographical factors. The purpose of this study was to establish and strengthen policies on major trauma.

In this study, medical resources, including emergency medical systems and trauma care, were critical regional factors that need to be well-established to ensure timely and effective medical care. Having a well-established emergency medical system, as well as adequate trauma care facilities and sufficient beds and personnel, can significantly impact outcomes of emergency situations and foster prompt and effective care for patients with severe injuries. Therefore, ensuring adequate medical resources is crucial for the well-being of a region’s population. Studies in the United States have shown that, after improving the emergency medical system, the preventable death rate was reduced [55–57]. To that end, it is necessary for people to perceive trauma as a regional or national matter rather than an individual matter. When
assigning emergency medical resources, few studies have recommended considering regional characteristics to decrease mortality due to major trauma and to establish integrated trauma care systems from injury to discharge [58,59].

In previous studies, it has been suggested that in order to reduce the disparities in mortality rates that are attributed to socioeconomic factors such as gender, race, and region, it is necessary to establish prevention policies and programs tailored to high-risk areas and populations at the national and regional levels [30,37,39,52]. Policies based on injury prevention are needed, as shown by the effectiveness of policy and enforcement interventions such as speed limits, traffic lights, speed-camera enforcement to reduce injury and mortality rates due to car accidents, and installation of smoke alarms to reduce fire-related incidents [31,33].

It appears that the impacts of medical resources and environmental factors on trauma outcomes are not attributed to a single factor, but rather a complex interplay of multiple factors. In order for such strategies to be realized, several factors should be considered. First, more domestic trauma case studies should be conducted, as there have been too few conducted in Korea to fully understand the risk factors for major trauma. Among the 32 studies [16,24–54] assessed herein, only two [34,51] analyzed domestic cases. Second, case studies of impairment should be also conducted, as there have been significantly fewer domestic studies addressing impairment due to trauma than those addressing death due to trauma. In addition, rather than using objective indicators, the domestic case studies employed relatively subjective indicators, including surveys, number of work absences after accidents, and availability of hospice wards. Finally, articles published in other countries have used various geographic variables such as time of transfer, type of vehicle for transfer, number of beds, and variables related to trauma centers. In future studies, Korea should consider incorporating similar geographic variables.

This systematic review has a few limitations. First, we focused only on geographic variables and excluded other variables. Second, we categorized geographic factors into socioeconomic, environmental, and medical-resource–related categories, and articles analyzing other topics were not considered. Despite these limitations, this study is meaningful as it presents the trends in trauma care, as determined through variables, analytical methods, and research outcomes.

In conclusion, although further research is needed, our study showed that geographic factors, including socioeconomic, medical resource, and environmental factors, such as population density, region (e.g., metropolis, rural), income levels of the area, and presence of trauma centers, appear to influence trauma outcomes. In order to reduce the incidence of death and disability due to trauma, it is important to establish appropriate care plans that take into account geographical factors. One approach could be to develop regional trauma care systems that address specific treatment difficulties in different areas.

SUPPLEMENTARY MATERIALS

Supplementary Table 1. Result of assess of study using QualSyst (Alberta Heritage Foundation for Medical Research)

Supplementary materials are available from https://doi.org/10.1541/ceem.23.009

ETHICS STATEMENT

Not applicable.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

FUNDING

None.

AUTHOR CONTRIBUTIONS

Conceptualization: BH, TJ; Data curation: BH, TJ; Formal analysis: BH, JJ; Methodology: BH, TJ; Writing–original draft: BH; Writing–review & editing: TW, JJ. All authors read and approved the final manuscript.

ORCID

Bona Hwang https://orcid.org/0000-0002-8745-3525
Taewook Jeong https://orcid.org/0000-0002-4495-3503
Jiyeon Jo https://orcid.org/0000-0003-0637-0830

REFERENCES

3. Hong TH, Lee SH, Kim HW, Jung MJ, Lee JG. Patterns of in-
33. Poulos RG, Hayen A, Chong SS, Finch CF. Geographic mapping
58. Kim WN. Political direction for establishing a patient centered emergency medical services system [Internet]. HIRA OAK Repository; 2020 [cited 2023 Mar 2]. Available from: https://repository.hira.or.kr/handle/2019.oak/2235
59. Lee KH. Establishment of regional emergency medical services system [Internet]. HIRA OAK Repository; 2020 [cited 2023 Mar 27]. Available from: https://repository.hira.or.kr/handle/2019.oak/2236
<table>
<thead>
<tr>
<th>Study</th>
<th>Question</th>
<th>Study design</th>
<th>Selection</th>
<th>Subject characteristics</th>
<th>Random allocation</th>
<th>Blinding investigators</th>
<th>Blinding subjects</th>
<th>Outcome</th>
<th>Sample size</th>
<th>Analytic method</th>
<th>Estimate of variance</th>
<th>Confounding variables</th>
<th>Result</th>
<th>Conclusion</th>
<th>Summary score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minei et al. [24]</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>0.0</td>
</tr>
<tr>
<td>Keeves et al. [25]</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>1.54</td>
</tr>
<tr>
<td>Young et al. [26]</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>1.72</td>
</tr>
<tr>
<td>Moshiko et al. [27]</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>1.54</td>
</tr>
<tr>
<td>Snyder et al. [28]</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>1.18</td>
</tr>
<tr>
<td>Fatovich et al. [29]</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1.81</td>
</tr>
<tr>
<td>Zandy et al. [30]</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>1.63</td>
</tr>
<tr>
<td>Wolf et al. [31]</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1.36</td>
</tr>
<tr>
<td>Gomez de Segura Nieva et al. [32]</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>1.54</td>
</tr>
<tr>
<td>Poulos et al. [33]</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1.81</td>
</tr>
<tr>
<td>Kim et al. [34]</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1.63</td>
</tr>
<tr>
<td>Brown et al. [16]</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1.00</td>
</tr>
<tr>
<td>Dinh et al. [35]</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1.90</td>
</tr>
<tr>
<td>Wang et al. [36]</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1.27</td>
</tr>
<tr>
<td>Irizarry et al. [37]</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1.45</td>
</tr>
<tr>
<td>Newman et al. [38]</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>NA</td>
<td>2</td>
<td>2</td>
<td>1.45</td>
</tr>
<tr>
<td>Razzaghi et al. [39]</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1.72</td>
</tr>
<tr>
<td>Jarman et al. [40]</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1.81</td>
</tr>
<tr>
<td>Brown et al. [41]</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>1.09</td>
</tr>
<tr>
<td>Pu et al. [42]</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1.81</td>
</tr>
<tr>
<td>Jarman et al. [43]</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1.81</td>
</tr>
<tr>
<td>Jarman et al. [44]</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2.00</td>
</tr>
<tr>
<td>Wandling et al. [45]</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>1.36</td>
</tr>
<tr>
<td>Brown et al. [46]</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0.81</td>
</tr>
<tr>
<td>Beaulieu et al. [47]</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1.00</td>
</tr>
<tr>
<td>Elkbulli et al. [48]</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1.72</td>
</tr>
<tr>
<td>Bhutiani et al. [49]</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0.63</td>
</tr>
<tr>
<td>Ciesla et al. [50]</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1.72</td>
</tr>
<tr>
<td>Lee et al. [51]</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1.63</td>
</tr>
<tr>
<td>Liu et al. [52]</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2.00</td>
</tr>
<tr>
<td>Chen et al. [53]</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1.72</td>
</tr>
<tr>
<td>Kloep et al. [54]</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1.09</td>
</tr>
</tbody>
</table>

NA, not applicable.
ROMIAE (Rule-Out Acute Myocardial Infarction Using Artificial Intelligence Electrocardiogram Analysis) trial study protocol: a prospective multicenter observational study for validation of a deep learning–based 12-lead electrocardiogram analysis model for detecting acute myocardial infarction in patients visiting the emergency department

Tae Gun Shin¹*, Youngjoo Lee²*, Kyuseok Kim³, Min Sung Lee⁴,⁵, Joon-myoung Kwon⁴,⁵,⁶; on behalf of the ROMIAE study group⁷

¹Department of Emergency Medicine, Samsung Medical Center, Sungkyunkwan University School of Medicine, Seoul, Korea
²Department of Emergency Medicine, Soonchunhyang University Seoul Hospital, Seoul, Korea
³Department of Emergency Medicine, CHA Bundang Medical Center, CHA University School of Medicine, Seongnam, Korea
⁴Medical Research Team, Medical AI Co, Seoul, Korea
⁵Artificial Intelligence and Big Data Research Center, Incheon Sejong Hospital, Incheon, Korea
⁶Department of Critical Care and Emergency Medicine, Incheon Sejong Hospital, Incheon, Korea
⁷The full list of the ROMIAE study group is listed in the Acknowledgments

Objective Based on the development of artificial intelligence (AI), an emerging number of methods have achieved outstanding performances in the diagnosis of acute myocardial infarction (AMI) using an electrocardiogram (ECG). However, AI-ECG analysis using a multicenter prospective design for detecting AMI has yet to be conducted. This prospective multicenter observational study aims to validate an AI-ECG model for detecting AMI in patients visiting the emergency department.

Methods Approximately 9,000 adult patients with chest pain and/or equivalent symptoms of AMI will be enrolled in 18 emergency medical centers in Korea. The AI-ECG analysis algorithm we developed and validated will be used in this study. The primary endpoint is the diagnosis of AMI on the day of visiting the emergency center, and the secondary endpoint is a 30-day major adverse cardiac event. From March 2022, patient registration has begun at centers approved by the institutional review board.

Discussion This is the first prospective study designed to identify the efficacy of an AI-based 12-lead ECG analysis algorithm for diagnosing AMI in emergency departments across multiple centers. This study may provide insights into the utility of deep learning in detecting AMI on electrocardiograms in emergency departments.


Keywords Myocardial infarction; Artificial intelligence; Electrocardiography; Deep learning
INTRODUCTION

Cardiovascular diseases such as acute myocardial infarction (AMI) and acute heart attacks are the leading causes of death worldwide, and it has been confirmed that 31.8% of deaths globally are due to cardiovascular disease. As of 2019, 18.6 million people worldwide have died from cardiovascular diseases, and by 2030 approximately 23.5 million people will die [1,2]. AMI has been reported to be the main cause of cardiovascular disease. Early AMI diagnosis is critical for reducing the incidence of complications and mortality by allowing a rapid reperfusion strategy, thereby reducing medical costs [3]. According to the 2020 international guidelines, the first important step in the initial treatment of patients with suspected AMI is to acquire a standard 12-lead electrocardiogram (ECG) test within 10 minutes after arriving at the emergency medical center and, if possible, immediately contact a specialist [4]. However, with non–ST-segment elevation (NSTE) acute coronary syndrome (ACS), ECG readings may be normal in approximately 30% of patients, even when immediately analyzed by an expert [4]. Expert reading is strongly recommended; however, depending on the region and medical environment, even if an ECG is acquired within 10 minutes of arrival, a cardiologist or emergency medicine specialist may be unavailable. Patient overcrowding is common even in high-level emergency medical centers. Additionally, owing to the scarcity of available human resources during the COVID-19 epidemic, the readability of ECG tests may be poor [5,6].

With the accelerating transformation of digital health, it is critical to utilize artificial intelligence (AI) to quickly diagnose a myocardial infarction. Accordingly, AI research is being introduced for fast and accurate ECG analysis of patients with chest pain and suspected myocardial infarction. We previously developed an AI-based 6- and 12-lead ECG analysis algorithm for diagnosing myocardial infarction. Based on external validation, the sensitivity, specificity, positive predictive value, and negative predictive value of this algorithm were 84.4%, 88.5%, 51.8%, and 97.5%, respectively [7]. In addition, the developed AI-ECG analysis algorithm showed high predictive power for the severity, mortality, and type of myocardial infarction (ST-segment elevation myocardial infarction [STEMI] and AMI) [7]. However, no studies have employed AI algorithms for AI-ECG analysis utilizing a multicenter prospective design for diagnosing AMI. Furthermore, the SPIRIT-AI (Standard Protocol Items: Recommendations for Interventional Trials–Artificial Intelligence) and CONSORT-AI (Consolidated Standards of Reporting Trials–Artificial Intelligence) guidelines recommend that researchers create a transparent and trustworthy model and conduct rigorous clinical trials to determine whether clinical efficacy exists [8,9]. Accordingly, we planned a prospective multicenter cohort study to validate the performance of the AI-ECG analysis algorithm for AMI detection.

METHODS

Ethics statement

This study protocol was reviewed by each institutional review board of the 18 emergency medical centers and has since been approved by the final committee. Informed consent will be obtained from either the patient or their legal representative. Additionally, individual IRB approval numbers will be included in the final report.

Trial design and setting

This prospective, multicenter, cohort study will be conducted to validate the diagnostic performance of an AI-ECG analysis algorithm for AMI among patients visiting the emergency department (ED) with acute chest pain or equivalent symptoms. Eighteen EDs in Korea, from university-level teaching hospitals, will participate in this study. These EDs receive approximately 800,000 patients annually and are capable of performing emergency cardiovascular angiography and percutaneous coronary interventions.
Participants

Inclusion criteria
The study population will include adult patients (> 18 years old) visiting the ED within 24 hours of the onset of chest discomfort or those who are clinically suspected of having an AMI with equivalent symptoms. Patients who arrive at the ED 24 hours after their first chest pain, those who experience aggravated chest pain within 24 hours prior to ED arrival, or those who experience recurring symptoms within 24 hours after ED arrival will be included.

Exclusion criteria
Upon arrival at the ED, patients with out-of-hospital cardiac arrest (OHCA), those who do not provide consent to participate in the study, those with traumatic chest pain or other diagnoses that are well-differentiated from myocardial infarction (such as pneumothorax), and those transferred from another hospital with confirmed AMI will be excluded. However, patients with a sustained return of spontaneous circulation after an OHCA or those transferred with suspected AMI will be included.

Deep learning model
In this study, an advanced algorithm based on a previously reported AI-ECG model, called AiTiA-MI (Medical AI Co), will be used to diagnose AMI [7]. The only input to this algorithm is the 12-lead ECG, and the output is the probability score of AMI, expressed from 0 to 100 to the first decimal place. Among the probability scores, a cutoff threshold of 99% sensitivity and 90% specificity is designated to classify the risk as low, intermediate, and high. The raw ECG data analyzed by the AiTiA-MI algorithm is a raw data format saved in general-purpose 12-lead ECG equipment. ECG data will be collected for each patient and analyzed separately, so AI-ECG analysis results will not affect the clinical decisions made by attending doctors. Raw digital ECG data will be used as the input and recorded for 10 seconds at a 500-Hz sampling rate. This algorithm judges the level of artifacts in the incoming 12-lead ECG and does not derive analysis results for participants whose data contains artifacts that can significantly affect diagnostic performance. In addition, for missing values, if data of more than 1 second are missing for more than one lead, the results will be subject to drop out.

Study protocol
There will not be any restrictions to the enrolled patients in terms of treatment because of their participation in this study, and standard care will be provided at each emergency center based on international guidelines (Fig. 1) [3,4]. The patients as well as medi-
Clinical staff will be blinded to the results analyzed by the AiTiA-MI algorithm. In other words, only the data will be prospectively collected and analyzed. The AI-ECG analysis results do not affect the treatment flow of the patients. Standard care refers to the first diagnosis of STEMI, as well as the diagnosis and exclusion of non-STEMI (NSTEMI) and unstable angina based on the 0/1- or 0/3-hour rule [4]. During the initial evaluation of a patient, it is essential to describe the onset and quality of chest pain and other complaints. Physicians will apply a 0-hour (baseline) cardiac biomarker and 12-lead ECG as essential tests. The 0-hour cardiac biomarkers and 12-lead ECG are mandatory tests for participation in this study, and if one test is missing, patients will be excluded from the study. Cardiac biomarkers and 12-lead ECG used for subsequent follow-ups are not essential tests. For example, if NSTE-ACS is suspected, 1- and 3-hour follow-up biomarkers are likely to exist in many cases; however, even if they are not present, the patients will not be excluded from the study. When the physician in charge reads a standard 12-lead ECG acquired within 10 minutes of arrival of the patient, a score equal to the possibility of AMI, from 0 to 10 points (in 1-point units; 0, no chance of AMI; 10, 100% chance of AMI), will be assigned and recorded.

When STEMI is suspected, emergency treatment will be administered according to hospital-specific protocols. Even if STEMI is not suspected, standard care will be administered according to the 0/1- or 0/3-hour rules. Therefore, physicians will repeatedly apply 1- or 3-hour cardiac biomarkers and an ECG, as needed. The AI-ECG algorithm will analyze the 0-hour ECG conducted after this process. Meanwhile, 1- or 3-hour follow-up ECGs, conducted based on the order of the physician, will also be used for subgroup analysis.

Data measurements

We will measure and collect the following baseline characteristic data at the time of the ED visit: age, sex, weight, body mass index (BMI), and height. The following clinical information will be collected: vital signs, Killip classification, risk factors (hypertension, diabetes, hyperlipidemia, smoking history, and family history of cardiovascular disease), coronary artery disease, MI, percutaneous intervention, coronary artery bypass graft surgery, chronic heart failure, chronic kidney disease, transient ischemic attack or stroke, peripheral artery disease, and COVID-19 vaccination (mRNA type and inoculation within 6 weeks before the index visit). Chief complaints and onset time (typical chest pain, atypical chest pain, or noncardiac chest pain), clinical risk score (HEART [history, ECG, age, risk factors, and troponin level] and GRACE [Global Registry of Acute Coronary Events] 2.0), AMI score (range, 0–10) suspected by the physician, route of ED visit, cardiologist call time, coronary angiography unit arrival time, door-to-balloon time, and intravenous thrombolytic data will also be collected [10–12]. The laboratory findings will be planned and measured as follows: 0-hour (initial tests conducted after ED admission) blood test (blood urea nitrogen, serum creatinine, hemoglobin, and high-sensitivity [hs]- troponin I or T), and 1- and 3-hour follow-up (if the follow-up was performed before invasive coronary angiography) of hs-troponin I or T, raw 0-hour ECG data, and 1- and 3-hour follow-up.

Other test results and clinical information related to the following final diagnoses will be collected: initial invasive coronary angiography results after the index visit and final diagnosis in the ED and at discharge. Chest radiography, coronary computed tomography angiography, echocardiography, treadmill test, single-photon emission computed tomography, positron emission tomography, and cardiac magnetic resonance imaging will be performed during a 30-day follow-up period before or after the index visit.

Reference standard

There may be gaps in the clinical protocols in the 18 emergency centers owing to differences in hospitals and medical staff, which may affect the diagnosis of ACS. Therefore, to minimize these limitations, a multicenter study will be conducted at a tertiary-level or certified cardiovascular hospital, where treatment will be performed according to the 0/1- or 0/3-hour rule based on international guidelines [4]. In addition, each center will use hs-troponin I or T rather than conventional troponin. Tests using point-of-care equipment will not be accepted as initial cardiac biomarkers. In addition, to establish a reference standard, two emergency medicine specialists from each center, as independent assessors, will perform final labeling for each patient to determine whether STEMI, NSTEMI, unstable angina, stable angina, or other differential diagnoses exist. The assessors will label a type of myocardial infarction. The labeling results of the two specialists will be compared, and in case of discrepancies, a third specialist will review the results. This review will be based on the latest guidelines of the American Heart Association and European Heart Society’s fourth universal definition of MI [13].

Coronary artery disease

This includes patients diagnosed with MI, unstable angina, or stable angina prior to the index visit.

Chronic kidney disease

This includes patients with glomerular filtration rate (GFR) < 60 mL/min/1.73 m² (GFR categories, G3a–G5) or markers of kidney
AI-ECG model for AMI detection

damage. We will review the patient's history and previous measurements to determine the duration of kidney disease; if the duration is >3 months, chronic kidney disease will be confirmed [14].

**Transient ischemic attack or stroke**
We will review the medical history of the patient to determine the existence of a previously diagnosed transient ischemic attack or cerebrovascular infarction according to the latest evidence [15].

**Peripheral artery disease**
This is a lower extremity peripheral artery disease with atherosclerotic obstruction from the aortoiliac segments to the pedal arteries [16].

**Chronic heart failure**
We will review the medical history of the patient to confirm the diagnosis of heart failure before the ED visit by performing a review of the electronic medical record (EMR) [17].

**HEART and GRACE 2.0 scores**
The HEART score is used to estimate the risk of major adverse cardiac events (MACEs) in patients presenting with chest pain to the ED. The GRACE 2.0 score is used to estimate the risk of death or MI in patients with ACS [10–12].

**Outcome variables**
The primary outcome is the diagnosis of an AMI during index admission. AMI includes type 1 and type 2 MIs, as defined in the fourth universal definition of myocardial infarction guidelines [13]. There may be differences in the 99th percentile upper limit of cardiac troponin levels according to the laboratory criteria of each participating hospital. In this study, the values will be based on the standards of each hospital. The secondary outcome is a 30-day MACE. MACE is defined as any cause of death, MI, stroke, target-vessel revascularization, or stent thrombosis occurring within 30 days of an index visit. Thirty days after the index visit, a telephone follow-up will be conducted and medical records (consultation, work-up, and diagnosis lists) will be checked to determine whether MACE have occurred. We will also use mortality data provided by Statistics Korea (Daejeon, Korea).

Audits of primary and secondary outcomes will be performed by three emergency medicine specialists blinded to the results of the AI-ECG analysis. These specialists will make decisions based on prospectively collected data according to the study protocol, chest pain, angina symptoms, history, and various examination records confirmed using the EMR. In case of disagreements, the principle of majority rule shall be followed.

**Sample size**
The sample size was calculated based on a negative predictive value of 97.5%, as established previously [7]. The sensitivity, specificity, \( \alpha \) error, \( \beta \) error, and prevalence rate were set as 84%, 88%, 0.05, 0.10, and 10%, respectively. The prevalence of AMI in adults who visit the ED for nontraumatic chest pain differs in the literature and is reported to range from 4% to 17% [3,18]. The study sample size was calculated based on a 10% prevalence rate. However, based on a dropout rate of 10%, 6,814 participants will be ultimately required. This calculation is based on the “bdpv” library of R ver. 4.1.0 (R Foundation for Statistical Computing) and a corresponding study [19].

**Analysis for main outcomes**
We will evaluate the performance of the AI-ECG analysis algorithm for the primary and secondary outcome variables. The accuracy metrics include area under the receiver operating characteristic curve, sensitivity, specificity, positive predictive value, and negative predictive value, along with 95% confidence intervals. We will also demonstrate the performance of the AiTiA-MI algorithm using two thresholds to guide clinical decisions, with probabilities described as continuous variables. The prespecified performance criteria (low-probability group, sensitivity ≥ 99.0%; high-probability group, specificity ≥ 90.0%) are defined based on previous studies [20,21]. Regarding the primary and secondary outcomes, the actual performance of the algorithm using these thresholds will also be analyzed.

**Other analyses**
The scheme of the comparative analysis of the diagnostic performance of the algorithm for the primary outcome is as follows: AI-ECG analysis versus HEART/GRACE 2.0 score comparison, AI-ECG analysis versus cardiac biomarker (initial hs-troponin I or T) comparison, and AI-ECG analysis versus the subjective AMI score provided by the ED physician regarding the initial 12-lead ECG. We plan to conduct subgroup analyses according to the following items: demographics (age, sex, and BMI), risk factors, past medical history, onset of chest pain (<3 or ≥3 hours), type of chest pain, type of MI (type 1 or type 2), type of ACS (STEMI, NSTEMI, unstable angina, NSTE-ACS, or total ACS), involvement of vessel territories (if ACS was diagnosed), and type of ECG (left bundle branch block, right bundle branch block, left ventricular hypertrophy, pacemaker rhythm, or post-return of spontaneous circulation).
**DISCUSSION**

The significance of this study is as follows. To the best of our knowledge, this is the first study to prospectively validate an AI-based 12-lead ECG analysis algorithm for AMI diagnosis in an external multicenter environment. Myocardial biomarker test levels only rise 3 to 6 hours after the onset of AMI and reach the highest level within 12 to 24 hours [4]. In contrast, changes in the ECG appear immediately upon the onset of AMI. Therefore, AI-ECG analysis can be more accurate and faster than myocardial biomarker tests in screening for AMI in the hyperacute state, which is the golden time for the patient. The present study is expected to provide a basis for this argument. This study will also partially verify whether the diagnostic performance of the AI-based 12-lead ECG analysis algorithm for AMI is maintained even in patients with a history of MI, valvular heart disease, congenital heart disease, and/ or chronic heart failure. By conducting subgroup analyses, the study will identify subgroups where the algorithm shows low diagnostic performance in detecting AMI. For example, in the case of blood cardiac biomarkers, such as hs-troponin I or T, false-positive confounders, such as renal disease and sepsis exist. With reference to this, the input data required to upgrade this algorithm in such cases will be determined, and insights will be obtained regarding whether the algorithm should be modified into a separate version rather than upgrading, thus pursuing model diversification. This study will trigger further validation and intervention research, particularly in multinational and multiethnic settings.

**ETHICS STATEMENT**

This study protocol was reviewed by each institutional review board of the 18 emergency medical centers and has since been approved by the final committee.

**CONFLICT OF INTEREST**

Kyuseok Kim is a member of the Clinical and Experimental Emergency Medicine Editorial Board. Min Sung Lee and Joon-myoung Kwon are researchers of Medical AI Co (Seoul, Korea); Joon-myoung Kwon is also the founder and stakeholder of Medical AI Co. However, they were not involved in the peer reviewer selection, evaluation, or decision process of this article. No other potential conflict of interest relevant to this article was reported.

**FUNDING**

None.

**ACKNOWLEDGMENTS**

The full list of the ROMIAE study group: Sung Phil Chung (Department of Emergency Medicine, Yonsei University College of Medicine, Seoul, Korea), Eunah Han (Department of Emergency Medicine, Yonsei University College of Medicine, Seoul, Korea), Dong Hoon Kim (Department of Emergency Medicine, Gyeongsang National University College of Medicine, Jinju, Korea), Sung Hyuk Choi (Department of Emergency Medicine, Korea University College of Medicine, Seoul, Korea), Sung-Jun Park (Department of Emergency Medicine, Korea University College of Medicine, Seoul, Korea), Hanjin Cho (Department of Emergency Medicine, Korea University Ansan Hospital, Ansan, Korea), Sejoong Ahn (Department of Emergency Medicine, Korea University Ansan Hospital, Ansan, Korea), Mi Jin Lee (Department of Emergency Medicine, Kyungpook National University School of Medicine, Daegu, Korea), Haewon Jung (Department of Emergency Medicine, Kyungpook National University School of Medicine, Daegu, Korea), Han Sung Choi (Department of Emergency Medicine, Kyung Hee University College of Medicine, Seoul, Korea), Seok Hoon Ko (Department of Emergency Medicine, Kyung Hee University College of Medicine, Seoul, Korea), Ki Young Jeong (Department of Emergency Medicine, Kyung Hee University College of Medicine, Seoul, Korea), Yonghee Lee (Department of Emergency Medicine, Chung-Ang University School of Medicine, Bundang, Korea), Jong Eun Park (Department of Emergency Medicine, Samsung Medical Center, Seoul, Korea), Taerim Kim (Department of Emergency Medicine, Samsung Medical Center, Seoul, Korea), Heajin Chung (Department of Emergency Medicine, Soonchunhyang University College of Medicine, Asan, Korea), Won Young Kim (Department of Emergency Medicine, Asan Medical Center, Seoul, Korea), June-sung Kim (Department of Emergency Medicine, Asan Medical Center, Seoul, Korea), Young Gi Min (Department of Emergency Medicine, Ajou University School of Medicine, Suwon, Korea), Bangshill Rhee (Department of Emergency Medicine, Ajou University School of Medicine, Suwon, Korea), Chul Han (Department of Emergency Medicine, Ewha Womans University Mokdong Hospital, Seoul, Korea), Keon Kim (Department of Emergency Medicine, Ewha Womans University Mokdong Hospital, Seoul, Korea), Jaehol Yoon (Department of Emergency Medicine, Jeonbuk National University Hospital, Jeonju, Korea), So Eun Kim (Department of Emergency Medicine, Jeonbuk National University Hospital, Jeonju, Korea), Eujene Jung (Department of Emergency Medicine, Chonnam National University Hospital, Gwangju, Korea), Woo Jeong Kim (Department of Emergency Medicine, Jeju National University Hospital, Jeju, Korea), Ji Hwan Bu (Department of Emergency Medicine, Jeju National University Hospital, Jeju, Korea), Je Hyeok Oh (De-
Department of Emergency Medicine, Chung-Ang University College of Medicine, Seoul, Korea), Chiuwon Ahn (Department of Emergency Medicine, Chung-Ang University College of Medicine, Seoul, Korea), Myeong Namgung (Department of Emergency Medicine, Chung-Ang University College of Medicine, Seoul, Korea), Jeong Yeol Seo (Department of Emergency Medicine, Hallym University Medical Center, Seoul, Korea), Dong Won Kim (Department of Emergency Medicine, Hallym University Medical Center, Seoul, Korea), Tae Ho Lim (Department of Emergency Medicine, Hanyang University College of Medicine, Seoul, Korea), Yongil Cho (Department of Emergency Medicine, Hanyang University College of Medicine, Seoul, Korea), Jae Seong Kim (Department of Critical Care and Emergency Medicine, Incheon Sejong Hospital, Incheon, Korea), Seong Beom Oh (Department of Emergency Medicine, Dankook University College of Medicine, Cheonan, Korea), Jong-Hwan Jang (Medical AI Co, Seoul, Korea), Yong-Yeon Jo (Medical AI Co, Seoul, Korea).

AUTHOR CONTRIBUTIONS

Conceptualization: KK; Formal analysis: MSL; Investigation: MSL; Methodology: all authors; Project administration: KK, JK; Resources: JK; Software: MSL, JK; Supervision: KK; Validation: KK, TGS; Writing–original draft: MSL; Writing–review & editing: all authors. All authors read and approved the final manuscript.

ORCID

Tae Gun Shin https://orcid.org/0000-0001-9657-1040
Youngjoo Lee https://orcid.org/0000-0000-0728-2280
Kyuseok Kim https://orcid.org/0000-0002-7991-9428
Min Sung Lee https://orcid.org/0000-0001-9247-2432
Joon-myoung Kwon https://orcid.org/0000-0001-6754-1010

REFERENCES

A case report of furosemide extravasation in the hand: a rare cause of compartment syndrome

Sertaç Güler, Dilber Üçöz Kocaşaban

Department of Emergency Medicine, Ankara Training and Research Hospital, University of Health Sciences, Ankara, Turkey

In emergency departments, many drugs, fluids, and materials for medical examinations and treatment are typically administered to patients intravenously. One of the most common complications of the intravenous bolus or infusion of drugs is extravasation injuries. These injuries may cause certain morbidities for the patient, increase the cost of treatment, and prolong hospital stays. At the same time, these injuries also carry medicolegal risks for health personnel. Furosemide is a potent diuretic that is commonly used in emergency departments for volume overload conditions. To the best of our knowledge, there have been no cases reported in the literature of furosemide-induced extravasation injury with subsequent compartment syndrome that has required surgical intervention. Presented herein is the case of a 70-year-old female patient who was administered intravenous furosemide from the dorsum of the left hand and whose extravasation injury progressed to compartment syndrome requiring an emergency fasciotomy.

Keywords: Compartment syndromes; Emergency medicine; Extravasation of diagnostic and therapeutic materials; Furosemide; Case reports

What is already known

One of the most common complications of the intravenous bolus or infusion administration of drugs or fluids is extravasation injuries in emergency departments. Many drugs, fluids, and materials for medical examinations and treatment may cause these types of injuries and may even result in compartment syndrome. Furosemide is a potent diuretic that is commonly used in emergency departments under general volume overload conditions.

What is new in the current study

To the best of our knowledge, this is the first case reported in the literature of furosemide-induced extravasation injuries with subsequent compartment syndrome that required surgical intervention.

How to cite this article:


This is an Open Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (https://creativecommons.org/licenses/by-nc/4.0/).
INTRODUCTION

Intravenous (IV) fluids, drugs, or radiological contrast agent administration in emergency departments (EDs) pose a potential risk of extravasation injuries. Due to damage to the vascular endothelium for a variety of reasons, fluids or drugs leak into the surrounding tissue and may progress from minor sequelae to compartment syndrome that could possibly result in amputation and organ loss [1-4].

Furosemide is a drug that we frequently administer through the IV route in EDs [5]. To the best of our knowledge, there have been no cases reported in the literature that have progressed to compartment syndrome after extravasation due to IV furosemide administration. Presented herein is a case of a 70-year-old female patient who was administered IV furosemide on the dorsum of the left hand 3 days prior in another hospital and was diagnosed with compartment syndrome at Ankara Training and Research Hospital.

CASE REPORT

A 70-year-old female patient was admitted to the ED with complaints of pain, swelling, and redness in the dorsum of the left hand. An IV bolus of furosemide was administered to the patient 3 days prior in another hospital through vascular access in the dorsum of the left hand. In the meantime, the patient exhibited swelling and pain in the dorsum of the left hand. The catheter was removed, and the patient was subsequently discharged and advised to keep her left hand and arm elevated. There was no other medication or fluid administered through the same IV line. The patient had a history of atrial fibrillation, congestive heart failure, and hypertension, and regularly underwent treatment using metoprolol, furosemide, acetylsalicylic acid, and amlodipine. The patient had no history of any other drugs, substances, or history of smoking and alcohol use. There was no history of trauma or human/animal or insect bites on the patient's left hand. During the physical examination, the vital signs of the patient were stable. There was widespread swelling, redness, ecchymotic areas, pallor, coldness, and pain with movement in the left hand and wrist, extending to the distal forearm. As stated before, a bullous lesion that measured approximately 3 × 3 cm was observed on the dorsum of the left hand (Fig. 1). The nerve examination of the patient was normal, but there was limited flexion in the left wrist. On the bedside superficial ultrasonography, approximately 3 cm of heterogeneous fluid collection was observed in the thickest part of the left-hand dorsum in addition to an increase in soft tissue thickness. No acute pathology was observed in the left upper extremity arterial and venous Doppler ultrasonography of the patient. Laboratory results of the patient were within normal limits. The patient underwent a consultation with the plastic surgery department and was given a preliminary diagnosis of extravasation injury/compartment syndrome. Decompression therapy was applied to the patient in the ED. Dense heterogeneous fluid was aspirated by the plastic surgeon and the patient was admitted to the plastic surgery department for a fasciotomy. On the 5th day after the surgical procedure, the fasciotomy scar was closed without the need for a skin graft. The patient was discharged 1 week afterwards and instructed to return for a polyclinic check-up examination. Sensory and motor examination was completely normal upon discharge.

Written informed consent was obtained from the patient, but the patient did not allow photographs of the hand to be taken or shared after the surgical procedure or during discharge. The Institutional Review Board approval was not required as it was an anonymously submitted case and did not contain any identifying information.

DISCUSSION

Furosemide is frequently used as a potent loop diuretic in EDs for the treatment of ascites due to cirrhosis and peripheral, pulmonary, or generalized edema. Its main use in the ED is the optimization of the volume status of a patient in systolic and diastolic heart failure. It can be administered as either an IV bolus or infusion [5]. The preferred way to obtain rapid systemic responses from the treatments applied in EDs is through the parenteral route. However, IV therapy may also have potentially significant

Fig. 1. Image shows the left hand of the patient. Global tissue swelling, paleness, some ecchymotic areas, and a big bullous lesion in the dorsum of the left hand are markedly observed.
Furosemide extravasation

In the emergency medicine literature on these injuries, vasopressor agents [1,4], high-concentration dextrose solutions [3,6,7], radiographic contrast agents [2,8,9], peripheral parenteral nutrition [10], antiarrhythmic and sedative-hypnotics [11,12], and antibiotics [1,4] have been implicated and frequently reported. There have not been any adult cases reported in the literature regarding extravasation injuries and compartment syndrome associated with the use of IV furosemide. One defined case of a patient who was under 18 years of age was found, but it was not presented as a classic case report with a discussion of its management and prognosis [1]. To the best of our knowledge, the case presented herein is the first case report in which this association was revealed in the literature.

Risk factors for extravasation injuries may be related to the material used, the patient, the drug or IV fluid, or the clinician. Conditions such as using vascular access material that is larger than the diameter of the vein or the use of metal needles, improper technique, poorly fixed catheters, or vascular access on or near a mobile joint such as the dorsum of the hand, wrist, or elbow, increase the likelihood of such injuries [1,4]. Conditions such as extreme age, lymphedema, and decompensated blood flow are also among the risk factors related to the patient [1,4].

The patient herein was also a relatively old and edematous patient, and the vascular access was on the dorsum of the hand. In a meta-analysis that investigated the efficacy of administering vasopressors through a larger vascular access (such as central venous catheters) to avoid the risk of complications, it was revealed that the infusion of vasopressors through a peripheral IV line did not have a significant effect on the direct complication rate [13]. In order to prevent extravasation injuries in the ED, it may be a rational precaution to administer high-risk agents through larger IV lines, but this is a well-known situation with an increased risk of infection and is time-consuming for emergency treatment. Again, in a study that investigated the safety of the peripheral administration of norepinephrine in terms of the risk of extravasation, the risk was determined to be quite low [14]. Hyperosmolar solutions, vasoconstrictive agents, cytotoxic agents, and substances that are not at physiological pH carry a higher risk for extravasation injuries [4]. However, in a study where hyperosmolar agents, such as 3% hypertonic saline or mannitol, were administered to 192 patients through the peripheral IV route, the occurrence of extravasation was not observed [15]. The administration of furosemide, despite its relatively low osmolarity and nonacidic pH, caused extravasation injury in the patient in the current study, which has not been reported in the literature to date.

Nonpharmacological treatment options for extravasation injuries include stopping the infusion, withdrawing the needle or catheter, elevating the affected extremity, applying a warm/cold compress to the involved area, and debridement and excision of necrotic tissue [4]. Again, before this stage, surgical flushing with normal saline may be attempted for some hyperosmolar agents [4]. For the patient in this study, decompression was first applied to drain the fluid by a plastic surgeon, and then the patient was hospitalized for a fasciotomy. Although extravasation injuries rarely cause compartment syndrome, it is possible for compartment syndrome to occur from any such injury, as in this case. Although it is difficult to distinguish the precise cause, whether it is the volume status of the fluid or the drug, or the vesicant property of the drug (furosemide) or both, no other cases of compartment syndrome caused as the result of IV furosemide specifically have been reported in the literature thus far.

Pharmacological treatment options for extravasation injuries include hyaluronidase, phenolamine, terbutaline, topical nitroglycerin, and topical hydrocortisone [1,3,6]. In particular, hyaluronidase has been reported to be effective for the extravasation of many hyperosmolar agents and is gaining increasing importance in emergency medicine literature [3,6]. It exerts its effect mainly through the hydrolysis of hyaluronic acid, which is responsible for cellular adhesion. By weakening the viscosity of intercellular binding, it facilitates the passage of extravasated fluid back to the vascular bed [3,6]. For the patient in this study, no medication was administered and the treatment performed was mainly surgical in nature.

As a limitation, the patient did not allow for postoperative photographs of her hand to be taken. For this reason, it was not possible to share the postoperative recovery photos of the patient. We did not have the opportunity to measure the compartment pressure of the hand, but we consider the clinical status of the patient to be more important than pressure values for the emergency medicine literature.

Extravasation injuries due to IV fluids or drugs may progress to compartment syndrome in EDs. Furosemide has not been reported in the literature in this regard to date. It should be kept in mind that this agent, which is frequently administered through IV routes in EDs, may cause this complication. Compartment syndrome carries many health risks for the patient and awareness of its risks is important for patient management and potential medicolegal litigation.
CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

FUNDING

None.

AUTHOR CONTRIBUTIONS

Conceptualization: all authors; Methodology: all authors; Data curation: all authors; Formal analysis: DUK; Writing—original draft: SG; Writing—review & editing: all authors. All authors read and approved the final manuscript.

ORCID

Sertaç Güler https://orcid.org/0000-0002-6266-6145
Dilber Üçöz Kocaşaban https://orcid.org/0000-0002-7473-1434

REFERENCES

Colonic high-pressure barotrauma with tension pneumoperitoneum

Sasikumar Mahalingam¹, Gunaseelan Rajendran¹, Saravanan Muthusamy², Manu Ayyan², Shirshendu Dhar², Shivani Karn², Mounika Gara², Vignesh Anandharaj²

¹Department of Emergency Medicine, Aarupadai Veedu Medical College and Hospital, Vinayaka Missions Research Foundation (DU), Puducherry, India
²Department of Emergency Medicine, Jawaharlal Institute of Postgraduate Medical Education and Research, Puducherry, India

A 22-year-old male patient with a history of alcohol consumption and no known comorbidities presented to the emergency department with a complaint of severe abdominal pain after accidentally sitting over an air vent and experiencing high-pressure air insufflation per rectum. Physical examination revealed a grossly distended abdomen with diffuse tenderness, rigidity, and absent bowel sounds. Abdominal radiography and computed tomography showed tension pneumoperitoneum (Fig. 1), leading to a diagnosis of colonic high-pressure barotrauma.

Emergency surgery was performed, revealing mid-transverse colon perforation and multiple serosal tears and contusions over the caecum and other parts of the colon (ascending, transverse, descending, and descending sigmoid colon). Primary closure of the perforation and diversion ileostomy were performed, followed by a 10-day stay in the intensive care unit. The patient was ultimately discharged with follow-up instructions. This case illustrates the potential dangers of air compressor injuries and emphasizes the need for prompt recognition and surgical intervention in cases of high-pressure intestinal barotrauma to prevent serious complications.

Intestinal barotrauma resulting from compressed air is a rare occurrence that typically arises due to accidental or sexual injury in industrial areas. The injury results when a high-pressure air jet column penetrates the anal sphincter barrier, leading to intestinal barotrauma upon burst pressure. The severity of the injury depends on various factors, such as air pressure, airflow velocity, anal resting pressure, and the distance between the source and the anus [1]. Tension pneumoperitoneum differs from simple pneumoperitoneum due to the presence of enormous tension in the peritoneal space, which can lead to fatal hemodynamics (inferior vena cava and...
splanchnic circulation) and respiratory compromise (elevation of the diaphragm) [2]. While injuries can range from mild to moderate (such as cat scratch colon) or severe (such as perforation or blowout) [3], injuries above and at the rectosigmoid junction are more common, while those distal to the rectosigmoid junction are seldom reported.

Expectant management is appropriate for individuals without clinical or radiological signs of peritonitis. In contrast, patients with peritonitis symptoms require surgical intervention, such as rectal tube decompression, intraoperative bowel decompression, resection of severe injuries, and perforation repair with proximal diverting colostomy or enterostomy if the bowel integrity is questionable [4]. In such cases, emergency physicians play a vital role in promptly diagnosing the condition, converting a tension pneumoperitoneum into an open pneumoperitoneum, and reducing the delay in surgical intervention. Death can occur due to complications such as air embolism, fat embolism, respiratory failure, acute heart failure, and hyperacute abdominal compartment syndrome, highlighting the importance of prompt diagnosis.

ETHICS STATEMENT

Informed consent for publication of the research details and clinical images was obtained from the patient.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

FUNDING

None.

AUTHOR CONTRIBUTIONS

Conceptualization: S Mahalingam, GR, S Muthusamy, SK, MG, VA; Data curation: S Mahalingam, GR, MA, MG, VA; Methodology: S Mahalingam, GR, S Muthusamy, SD; Writing–original draft: S Mahalingam, GR, S Muthusamy, SK; Writing–review & editing: all authors. All authors read and approved the final manuscript.

ORCID

Sasikumar Mahalingam https://orcid.org/0000-0002-6681-8388
Gunaseelan Rajendran https://orcid.org/0000-0002-1280-209X
Saravanan Muthusamy Not available
Manu Ayyan https://orcid.org/0000-0002-2541-5769
Shirshendu Dhar https://orcid.org/0000-0001-8346-4123
Shivani Karn Not available
Mounika Gara https://orcid.org/0000-0002-8981-6836
Vignesh Anandharaj Not available

REFERENCES

Perinatal carbon monoxide poisoning with fetal and maternal carboxyhemoglobin measurements

Dean T. Odegard¹,², Michael E. Mullins²

¹Department of Pediatrics, St. Louis Children’s Hospital, St. Louis, MO, USA
²Division of Medical Toxicology, Department of Emergency Medicine, Washington University School of Medicine, St. Louis, MO, USA

Dear Editor,

Carbon monoxide (CO) poisoning is the leading cause of pediatric poisoning mortality in the United States—most frequently resulting from house fires or unintentional indoor CO exposures—and leads to about 5,000 pediatric emergency department visits annually [1–3]. In pregnancy, the fetus is particularly susceptible to CO [4]. Fetal hemoglobin has a higher affinity than adult hemoglobin for both oxygen and carboxyhemoglobin (COHb). Fetal COHb concentration may be about 15% higher in the fetus than in the mother [5], but simultaneous measurements in vivo are rare. Longo and Hill [6] concluded that to normalize fetal COHb, a pregnant woman would need to continue oxygen therapy five times longer than it took for her own COHb to normalize. We describe a case of antepartum CO poisoning at term, treated with caesarean section and normobaric oxygen with measurement of maternal and fetal COHb within 2 hours of one another.

A 21-year-old woman (who has been pregnant twice and given birth once) suffered acute unintentional CO poisoning at estimated gestational age of 38 weeks and 5 days. She had adequate prenatal care, normal prenatal screenings, and a positive Group B Streptococcal culture. Her only regular medication was a prenatal vitamin and she reported intermittent cannabis use. She consented to sharing anonymized clinical details for herself and her baby.

The mother reported a headache that rapidly worsened over an hour soon after a technician had been working on pipes and insulation in the attic of the residence earlier that day. She called a family member for assistance. Her relative found her confused, nauseated, and lying on the kitchen floor about half an hour later and summoned an ambulance. Paramedics recorded syncope, headache, lightheadedness, and nausea. She denied chest pain, dyspnea, contractions, or vaginal bleeding. Blood glucose was 97 mg/dL (5.4 mmol/L). In the emergency department, she additionally reported paresthesia of lips, hands, and feet. She was sleepy but oriented, tachycardic (122 beats/min), and normotensive with room air oxygen saturation of 96%. Arterial blood gases after 30 minutes of 100% oxygen (15 L/min by nonrebreather mask) and a total of 90 minutes after cessation of CO exposure included COHb of 11.3%, pH of 7.44, pCO₂ of 29 mmHg, and pO₂ of 287 mmHg. Her white blood cell count was 10.4 K/mcL, hemoglobin 9.1 g/dL, and bicarbonate 20 mmol/L. Urine drug screen was positive only for cannabinoids. Electrocardiography indicated normal sinus rhythm with sinus arrhythmia. Her cervix was 4 cm dilated and 70% effaced, with uterine contractions at 5-minute intervals. Fetal heart tracing was category III, with a rate of 130 beats/min, minimal variability, and occasional variable decelerations. Fetal tocometry improved to category II after 60 minutes of 100% fraction of inspired oxygen (FiO₂), but concern for fetal distress compelled urgent caesarean section. Delivery of the baby boy was uncompli-
ated, with spontaneous cry, 60 seconds of delayed cord clamping, Apgar scores of 8 and 9, and a birth weight of 3,460 g. Time of birth was 3.5 hours after cessation of CO exposure. He immediately received continuous positive airway pressure at 6 cmH2O and 100% FiO2. Venous cord blood gases included COHb of 14.3%, pH of 7.36, pCO2 of 42 mmHg, pO2 of 21 mmHg, and base excess of –2. He was transferred to a pediatric hospital with a neonatal intensive care unit (NICU), where capillary blood gases at 4.5 hours of life showed pH of 7.43, pCO2 of 31 mmHg, pO2 of 103 mmHg, and base excess of –2.9. COHb had fallen to 0.7% and methemoglobin was 0.5%. He transitioned to room air. He fed appropriately, and we removed his umbilical venous catheter the next day. He went home on the 3rd day of life. The clinical course is summarized in Fig. 1.

Retrospectively, we estimate a peak COHb of 19% in the mother, but her history and symptoms (tachycardia, confusion, headache, and alteration in consciousness) suggest a COHb concentration in the range of 30% to 50% [4]. Importantly, blood COHb concentrations commonly do not correlate with tissue concentrations, initial symptoms, or patient outcomes [7]. Poor fetal outcomes may occur even despite maternal survival [8–10]. Symptoms of CO poisoning in infants and young children may be more difficult to detect. A case series of CO poisoning in children aged 4 days to 19 months surprisingly found a higher mean COHb in five asymptomatic patients (24%) than in seven symptomatic patients (16%) [11].

Hyperbaric oxygen therapy (HBOT) is safe for pregnant women with CO poisoning [12]. Guidelines recommend HBOT for all CO poisonings in pregnant women regardless of clinical status or COHb concentration [13]. Recommendations for neonatal HBOT are based on expert consensus. Liebelt [14] suggested infants younger than 6 months who present with lethargy, irritability, or poor feeding and have a known CO exposure for which an adult receives HBOT, should also receive HBOT. The Israeli Naval Medical Institute employs HBOT for CO-poisoned children of any age with either evidence of myocardial ischemia, COHb greater than 25%, or any neurologic symptom [15].

Risks of HBOT in neonates include seizures from central nervous system oxygen toxicity, hypothermia, potential premature closure of the ductus arteriosus, transport-related decompen-sation, and barotrauma. A chest radiograph should be obtained prior to HBOT to rule out neonatal lobar emphysema or pneumothorax. Myringotomy, sometimes considered for patients too young to reliably equalize middle ear pressure via the Eustachian tubes or with active middle ear effusions, is usually not necessary if the child is able to breastfeed or suck a pacifier during chamber pressurization [11]. To prevent distress or regurgitation, infants should be burped prior to ascent in the chamber.

In our case, fetal distress compelled urgent delivery. The interfacility transfer decision involved a choice between NICU services at a nearer tertiary care pediatric hospital and a more distant community hospital with HBOT. Difficulty arranging HBOT in our region, additional transport time, and the location of NICU services favored transport to the former. At 4.5 hours of life the infant had a normal COHb level and a normal neurologic exam. However, HBOT remains the recommended treatment for all pregnant women poisoned with CO, and future studies should address assessment of CO-poisoned neonates for delayed neurologic sequelae. This case supports the belief that fetal COHb is higher than maternal COHb.

Fig. 1. Timeline of clinical and laboratory events for the neonate (top) and the mother (bottom). Each tick mark represents 2 hours. COHb, carboxyhemoglobin; CPAP, continuous positive airway pressure.
ETHICS STATEMENT

This study did not require approval from the Institutional Review Board. Informed consent was obtained from the mother. Documentation of informed consent is kept by the author and available if requested.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

FUNDING

None.

AUTHOR CONTRIBUTIONS

Conceptualization: all authors; Data curation: DTO; Investigation: DTO; Project administration: all authors; Supervision: MEM; Writing–original draft: DTO; Writing–review & editing: all authors. All authors read and approved the final manuscript.

ORCID

Dean T. Odegard https://orcid.org/0000-0002-7093-6889
Michael E. Mullins https://orcid.org/0000-0001-8605-0217

REFERENCES