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Management of Embedded Unexploded Ordnance in Low-resource Settings: A Scoping Review

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Abstract

Objectives: When unexploded ordnance (UXO) is embedded in the body, the effect of explosive weapons used in conflict is amplified. Though relatively rare, such events present potentially devastating consequences for the patient and medical providers as routine diagnostic and therapeutic procedures hold potential to initiate detonation of the embedded UXO (eUXO). The objective is to identify and synthesize available literature relating to the management of eUXO in low resource settings.
Methods: A scoping review was conducted using PRISMA-ScR methodology to evaluate literature in all languages from all date ranges until January 31, 2024, discussing the management of casualties with eUXO, including types of ordnance, injury patterns, diagnostics, resource utilization, surgical interventions, and outcomes.
Results: Search strings identified 3,425 records. After title and abstract screening 3,397 were excluded yielding 18 for full text screening of which 5 were excluded. Therefore 13 reports were included in analysis. Data variable reporting was heterogeneous but themes and subthemes regarding safety, planning and communication emerged.
Conclusions: A scoping review was conducted to identify gaps in existing literature on the management of eUXO in low resource settings. Coordinated engagement from personnel representing a variety of clinical and non-clinical specialties is required to safely manage eUXO.

The use of explosive ordnance in conflict dates to the utilization of an early form of gunpowder in China during the 11th-century Song dynasty.[1] As civilizations have progressed, so too has the development of more efficient and destructive weapons (e.g., thermobaric and other high-energy explosives). Explosive ordnance inflicts devastating and longstanding consequences on individuals, populations, and societies from physical, psychological, and humanitarian perspectives.[2–4] The volume of explosive ordnance used in modern conflicts illustrates the scale of this harm. Tens of thousands of explosive munitions were employed during Operation Iraqi Freedom and Operation Enduring Freedom.[5] Airpower statistics released by the US Combined Force Air Component Commander from 2008-2021 showed an annual average of 3672 weapons released.[6,7] Data recorded by Action on Armed Violence (AOAV) in 2021 and 2022 shows that at least 32 136 civilian casualties were reported in 71 countries and territories across the globe by explosive weapons.[8] Such data are rarely available for less publicized conflicts in low-resource settings such as Myanmar, Sudan, and the Sahel.[9] In addition, improvised explosive devices (IEDs) continue to be utilized routinely in armed conflicts globally.[10,11]

One uncommon but potentially devastating consequence of explosive ordnance use is embedded unexploded ordnance (eUXO), when unexploded ordnance (UXO) or UXO components are embedded in the body of a patient.[12] This rare event presents extraordinary risks for the patient, medical providers, and scarce health care infrastructure as routine procedures have the potential to initiate the item of eUXO. The management of eUXO even in an open environment (e.g., in situ in a field, road, or open land) under controlled circumstances with personnel trained in explosive ordnance disposal (EOD) is a complex, dangerous and a resource-intensive undertaking. When encountering eUXO during the provision of medical care, the complexity, danger, and required resources are dramatically increased. In many cases, the presence of eUXO cannot be detected in the field and may not be discovered until a patient is already receiving care at a medical facility.[12,13]

The International Committee of the Red Cross (ICRC) "Removing Embedded Ordnance from Patients"[12] and Joint Trauma System Clinical Practice Guideline (JTS) "Unexploded Ordnance Management",[13] provide clinical, technical, and leadership guidance for the management of eUXO. However, to date a structured evaluation of the literature has not been conducted, including comparison of these guidelines to identify areas of concordance, discordance, and need for further research. As the global community struggles to contend with the direct and indirect long-term impacts of the use of explosive ordnance, understanding the scope and limitations of existing evidence on the diagnosis and management of eUXO is critical.

The application of translational science[14] (T) can answer the T0 question, "What are trustworthy[15] clinical practice guidelines (CPG) to treat eUXO in low-resource environment complex settings, such as humanitarian events and conflict, low- and low-middle income countries, or prolonged transport times?" (Figure 1) The objective of this T1 scoping review is to synthesize available literature relating to the management of eUXO and to identify gaps between existing guidelines. Data extracted from sources obtained by this search can be utilized in the T2 creation of trustworthy clinical practice guidelines utilizing modified Delphi methodology.

Methods

Investigators used the Preferred Reporting Items for Systematic reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR) methodology to conduct a scoping review of published peer-reviewed literature and non-peer-reviewed grey literature (e.g., governmental and non-governmental organizations (NGO) reports, conference papers, policy documents).[16] A pre-review protocol was archived in an open-access platform (Supplemental File 1).[17]

Search Strategy and Information

A strategy was developed querying databases including PUBMED, EMBASE/Elsevier, CINAHL/EBSCO, Global Index Medicus, Global Health/EBSCO, SCI Expanded/SSCI/AHCL/ESCI and Google Scholar as well as organizational websites of relevant stakeholders noted during the review of sources obtained (e.g., US Department of Defense, ICRC, Geneva International Center for Humanitarian Demining, United Nations Mine Action Service). Targeted keywords and database-specific search terms were used in Boolean search logic combinations. Search strings were developed utilizing structured index terms and database-specific language designed to capture records describing the diagnosis and treatment of eUXO in armed conflict and civilian use of explosive materials (e.g., "UXO", "ordnance", "munition", "explosive", "bombs", "Improvised explosive device", "Rocket Propelled Grenade", "firework", "pyrotechnic") (Supplementary Table 1).

Eligibility Criteria

Investigators expected that the literature relevant to the topic would be limited. Therefore, inclusion criteria were designed to be intentionally broad to capture all potentially relevant evidence. Eligible records included peer-reviewed reports, conference papers, and grey literature that addressed the management of eUXO including all intervention types or outcomes related to this subject (e.g., type(s) of explosive ordnance, detection methods, mitigation strategies, injury patterns, morbidity, mortality). No restriction on publishing date was stipulated given the limited existing data on

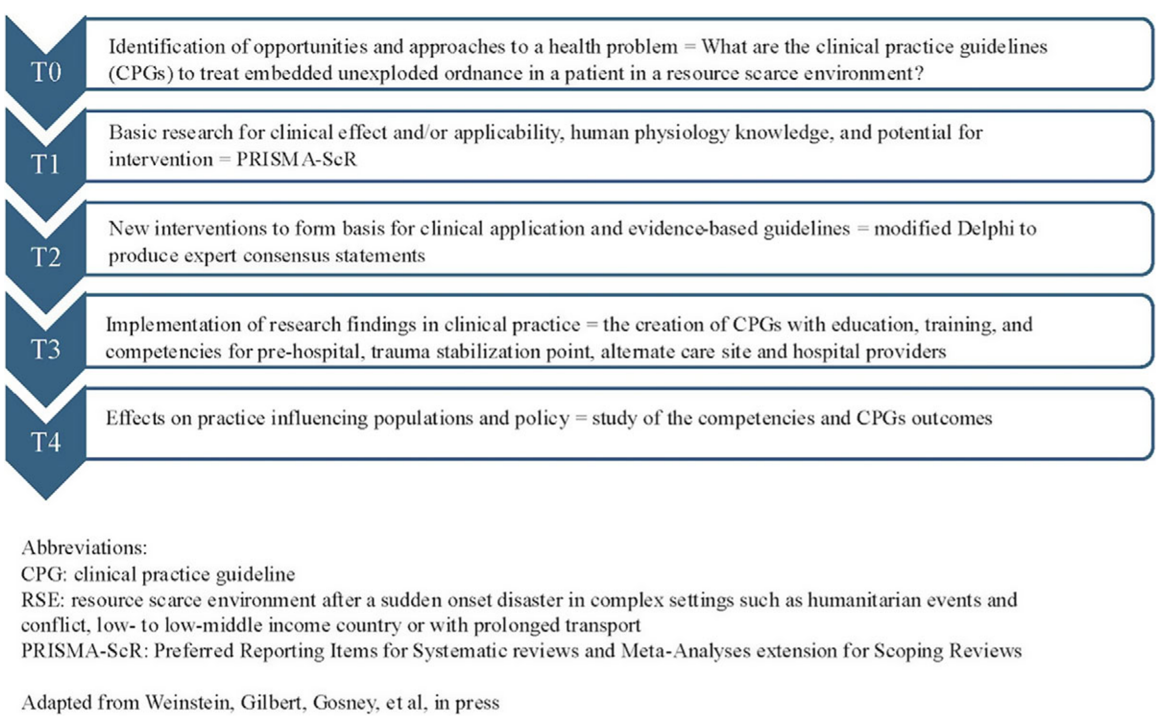

Figure 1. Translational Science Framework.

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the topic. All geographic regions and languages were eligible for inclusion. Lastly, both civilian and military patient populations were eligible for inclusion. Peer-reviewed reports or grey literature without full-text availability and literature solely describing eUXO management from a technical EOD standpoint without patient care considerations were excluded.

Data Management

Eligible records identified through the search strategy and inclusion criteria were compiled into Covidence® (https://www.covidence.org). Duplicate records were removed. Each record was reviewed by 2 investigators during title and abstract screening. All potentially eligible full-text reports were reviewed by 2 investigators during full-text screening. Discordance was arbitrated by a senior investigator (HW). Covidence® was used to develop a standardized data extraction form to facilitate uniform data collection from eligible literature. Extracted data included bibliographic details, patient demographics, injury characteristics (e.g., mechanism, involved anatomy, injury severity scores), explosive ordnance specifics (if available), mitigation procedures, diagnostic and therapeutic procedures utilized, patient outcomes, and author recommendations. Existing guidelines (i.e., ICRC and JTS) were analyzed separately through qualitative comparison and narrative synthesis of topic areas covered and recommendations provided.

Results

Results were reported in accordance with PRISMA-ScR guidelines (Figure 2; PRISMA ScR checklist presented in Supplementary Figure 1). Database searches identified 4058 records with 13 additional records identified through grey literature searches and review of reference list of eligible reports. Duplicate records (643) were removed. The remaining 3428 records were screened for relevance of which 3410 were excluded. Of the remaining 18 reports, 5 did not meet eligibility criteria and were excluded (i.e., did not describe the patient population of interest). Therefore, 13 reports were analyzed, representing a total of 90 patients from conflicts ranging from World War II to the US-led wars in Iraq and Afghanistan (Table 1).[14,18–29] Case reports (n = 10, 76.9%) accounted for the majority of reports included in analysis with one (7.7%) CPG, experimental model, brief report, and retrospective cohort review respectively accounting for the remainder of reports. Most reports (n = 11, 84.6%) presented data on patients treated at military medical facilities, with 3 reports (23.1%) presenting data on patients receiving care at local health facilities.

Geographic Distribution of Included Reports

The US was the geographic location most frequently represented by included reports (n = 6, 46.2%) with all cases involving the use of commercial pyrotechnics. Four reports (30.8%) presented data from the Middle East and North Africa region, and the remaining 4 reports (30.8%) presented data from multiple countries or were not associated with a clearly defined geographic region (e.g., CPGs) (Figure 3).

Patient and Injury Characteristics

Demographic reporting was inconsistent across included reports (Table 2). Seven reports (53.8%) provided demographic information (e.g., gender, age) of patients. All reported patients were male with a mean age of 29.7 years (Supplementary Table 2). Reports presenting data from outside the US (n = 8, 61.5%) all reported the involvement of a variety of eUXO. Types of eUXO included grenades, mortars, rockets, and anti-tank weapons. Anatomic regions of injury were presented by all but 1 report (n = 12, 92.3%) (Supplementary Figure 2). Multiple anatomic regions were frequently involved for each patient. The majority were of the injuries were upper extremity (n = 22, 40.7%) and chest injuries (n = 14, 25.9%). Head injuries were next (n = 7, 13.0%), followed by lower extremity injuries (n = 6, 11.1%), face (n = 3, 5.6%), neck (n = 1, 1.9%), and spine (n = 1, 1.9%). No recognized injury severity scores were presented.

Clinical and Other Outcomes

Mortality was reported in 3 reports (23.1% of reports).[21,23,27] Of these cases, 2 presented eUXO encountered during autopsy and the third presented eUXO in an expectant patient. All were deceased at time of eUXO identification. Complications following treatment were presented by 2 reports (15.4%),[20,28] including delay of care venous thromboembolism. Delays to care were associated with prolonged transport times and confusion over appropriate routing of patients with eUXO. For example, 1 patient was transported 244 minutes between a Level IV and Level I trauma center, increasing tourniquet time to 168 minutes.[28] Patient follow-up after discharge was presented by tw0 reports (15.4%).[22,25] No reports described functional outcomes.

Recommendations

Reports included in the thematic and subthematic analysis generally provided convergent recommendations. Key recommendations included: i) an emphasis on preparedness and safety through training, establishment of standard operating procedures, and inclusion of multidisciplinary subject matter experts; ii) eliminating the use of electrically powered surgical, diagnostic, and other medical equipment when eUXO suspected or identified; and iii) surgeons should consider en bloc resection with eUXO until it is rendered safe (Table 3). All reports discussed safety of prehospital personnel and considerations during patient transport. The need for strategies to identify eUXO early was emphasized, given the complexity of management and need for preparation at the receiving health facility. Cooperation between EOD and surgical teams was also identified as essential for safe eUXO management.

Guideline Comparison

The JTS and ICRC CPGs were evaluated for areas of concordance and discordance (Table 4). Areas of discordance were anticipated given the resource variation between a military trauma system with intact echelons of care and humanitarian surgical care in conflict and post-conflict settings or situations encountered by humanitarian demining teams. The ICRC guideline is exclusively directed towards health care professionals, while the JTS guideline is designed for both military and civilian personnel, focusing on the identification, handling, and disposal of eUXO. Safety of health care personnel and preservation of surgical resources and infrastructure is emphasized in both guidelines. ICRC guidance is predominantly focused on medical management of eUXO whereas the JTS provides a broader focus on the management of the entirety of the

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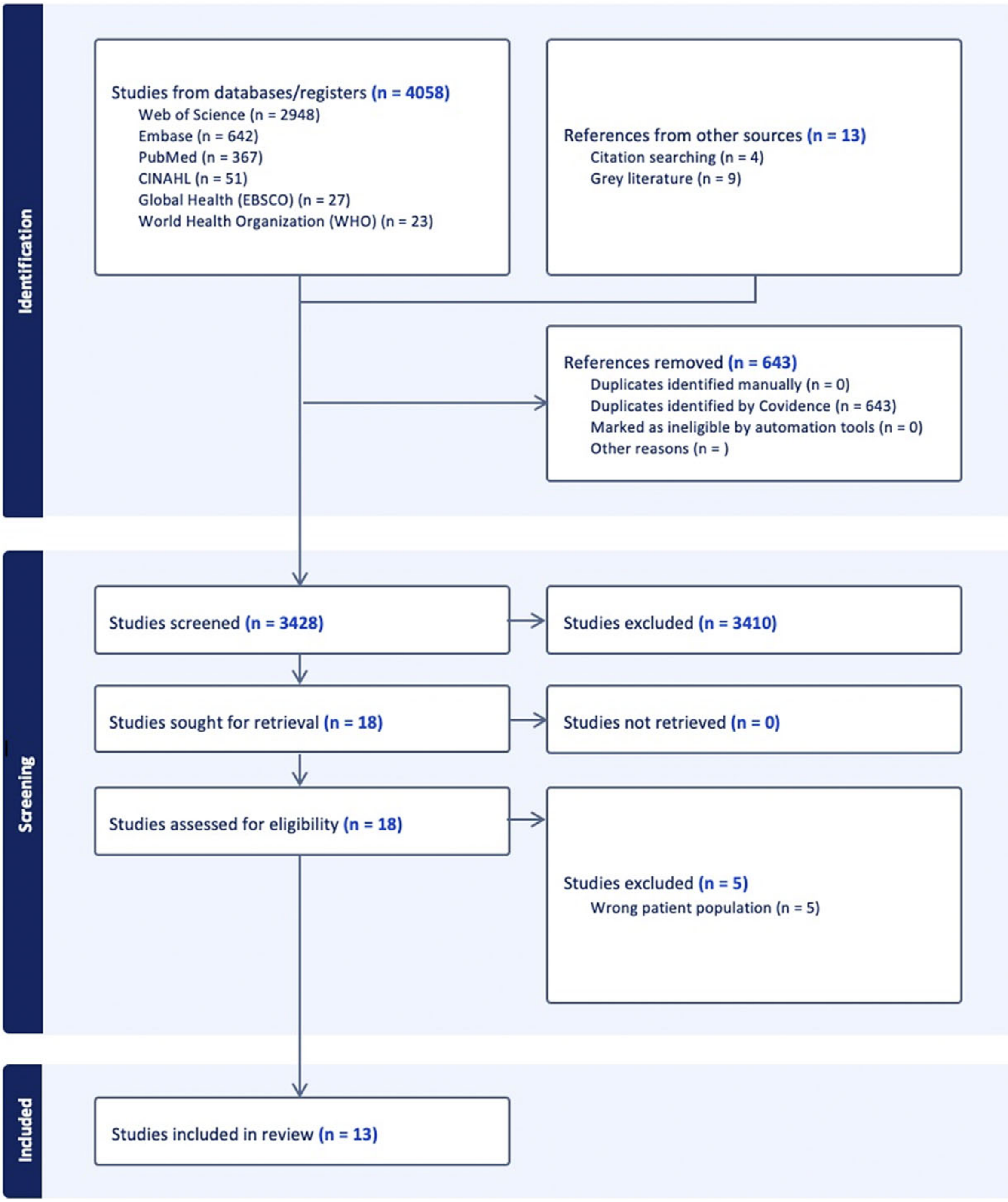

Figure 2. PRISMA-ScR Diagram.

eUXO incident, including command structures and the engagement of EOD expertise. Clinical management of patients with eUXO ranging from preoperative considerations to surgical techniques is central to the ICRC guideline, which also includes psychological impacts to the patient.

Limitations

This review has several limitations. Limited data exist on the management of eUXO, the majority of which is derived from case reports and expert guidelines. This limited the strength of conclusions that could be drawn from available literature. Nonetheless, this review provides a structured synthesis on the literature regarding management of eUXO to inform further research. Second, data collection and reporting were highly variable, consistent with findings from previous reviews of civilian conflict casualties in low-resource settings.[30] No centralized trauma registry exists that can be accessed by civilian, military, and international health care providers to inform performance improvement surrounding eUXO incidents. Narrative synthesis was used to present the most robust

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Table 1. Summary of peer-reviewed reports included in analysis

Study ID	Title	Study location	Study setting	Study design	Explosive ordnance type	Summary
Afshar 2022	Impaled unexploded mortar shell injury during the Iran-Iraq War 1980–1988	Iran	Military	Case series	60mm mortar	Letter to the editor that discusses several previous cases of eUXO and best practices for management.
Barrow 2023	Call the bomb squad: An interesting case of a retained explosive in the mouth	US	Civilian	Case study	Firework	Presents a case of an unexploded firework shell lodged in the face of a man aged 23 years.
Bartholomew 2023	Management of an unexploded intracorporeal firework in a low resource setting	US	Civilian	Case report	Firework	Describes surgical removal and post-operative course of a man aged 31 years with an unexploded 3-inch firework lodged in left upper thigh with exposed femoral vessels and absent distal pulses.
Clark 1987	A fatal wound from an unusual military projectile	US	Military	Case report	Cartridge actuated device	Presents a case of retained eUXO from the accidental detonation of a cartridge actuated device used to jettison aircraft wing fuel tanks.
High 2019	Impaled unexploded ordnance involving fireworks mishap	US	Civilian	Case report	Firework	Describes the surgical and post-operative course of a male aged 36 years who presented with a retained firework in brain parenchyma (right frontal lobe).
Howell 2016	Unexploded ordnance in an expectant patient	Multiple	Military	Case report	107-mm rocket	Discusses post-mortem care of male patient with retained eUXO from a rocket attack.
Lein 1999	Removal of unexploded ordnance from patients	Multiple	Military	Retrospective cohort	Multiple ordnance types	Presents a review of military cases of retained eUXO.
Oh 2018	Unexploded ordnance management	Multiple	Military	Clinical practice guideline	Not applicable	Clinical Practice Guide for the identification, removal, and safe management of eUXO.
Pengelly 2015	Home-made explosive found inside injured Afghan	Afghanistan	Military	Case report	IED	Case report of eUXO in a 22-year-old Afghan soldier with retained home-made explosive following a dismounted IED detonation.
Qin 2014	Microwave-induced thermoacoustic imaging for embedded explosives detection	Multiple	Not applicable	Experimental modeling	Not applicable	Modeling experiment to apply microwave-induced thermoacoustic imaging to explosive detection embedded in a synthetic biological tissue.
Spencer 1979	Accidental death by light anti-tank weapon: A dangerous autopsy?	US	Military	Case report	Projectile from light anti-tank weapon (M–72)	Autopsy report detailing the removal of a presumed unexploded projectile from the head of a deceased Marine Corps recruit.
Thaut 2018	An Impaled Potential Unexploded Device in the Civilian Trauma Setting	US	Civilian	Case report	Firework	Case report detailing the instance of a male civilian aged 44 years presenting with a close proximity blast injury to the right lower extremity.
Waqas 2012	A unique presentation of unexploded ordnance in a patient	Pakistan	Military	Case report	Rocket	Presents a case report of through-and-through rocket injury to the right lower extremity in a man aged 35 years including surgical management and post-operative course.

Abbreviations: eUXO – embedded unexploded ordnance; IED – improved explosive device; UXO – unexploded ordnance

findings possible within these limitations. This review did not evaluate the immediate or long-term psychological effects on patients and health care personnel associated with eUXO incidents, which fell outside the scope of this review's objectives. Despite these limitations, the findings of this review may be used to inform further preparedness initiatives and research strengthening the evidence base for guidelines on the management of eUXO in low-resource settings.

Figure 3. Geographic distribution of reports included in analysis.

Table 2. Proportion of included peer-reviewed reports presenting data variables of interest

Data variable	Number of reports[1,2] (n = 13)	Percent of reports[1]
Geographic region presented	13	100.0
Americas	6	46.2
Middle East North Africa	4	30.8
Sub-Saharan Africa	2	15.4
Other/multiple regions	4	30.8
Study design presented	13	100.0
Case Report	10	76.9
Model	1	7.7
Retrospective cohort	1	7.7
Clinical practice guideline	1	7.7
Type of facility presented	13	100.0
Military	11	84.6
Civilian or local health care facility	2	15.4
Combatant vs non-combatant status presented	9	69.2
Injury severity score presented	0	0.0
Mortality presented	4	30.8
Complications presented	3	23.1
Functional disability presented	0	0.0
Patient follow-up presented	3	23.1
Anatomic region of injury presented (by report)	12	92.3
Anatomic region of injury presented (by number of patients, n = 90)	54	60.0
Head	7	13.0
Face	3	5.6
Chest	14	25.9
Neck	1	1.9
Spine	1	1.9
Upper extremity	22	40.7
Lower extremity	6	11.1
Recommendations presented	11	84.6
Explosive ordnance identification	2	15.4
Patient transport	2	15.4
Surgical technique	4	30.8
Ordnance disposal plan	1	7.7
Multiple recommendation types	2	15.4

[1]Unless otherwise specified.
[2]N may be greater than 100% where multiple geographic locations or anatomic locations of injury specified.

Discussion

This review sought to synthesize the best evidence available regarding the management of eUXO to inform decision-making and the evidence base for CPGs on eUXO management in low-resource settings. Several "best practice" themes emerged in this review that discussed the importance of early eUXO identification, multidisciplinary involvement of EOD teams, safety of prehospital personnel, transport and surgical teams, and context-appropriate diagnostic and treatment modalities. Though rare, the potentially fatal consequences of eUXO management affecting both patient and surgical teams warrants dedicated attention. A coordinated approach from personnel representing a variety of clinical and non-clinical specialties is required to safely manage incidents involving eUXO.

Early Detection and Safety

The importance of early eUXO detection was emphasized by numerous reports given the range of technical expertise that must be mobilized to safely and effectively manage such situations.[13,19,22,23]

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Table 3. Recommendations and quotes derived from peer-reviewed reports included in analysis

Study ID	Recommendations	Quotes
Afshar 2022	Minimize the use of electrically powered equipment and remove combustible agents from the operating theater. Reduce the use of mechanical blood warmers, monitors, blood pressure gauges, and infusers or pumps to minimize the risk of static electrical discharge. Mechanical non-powered manual saws and drills rather than saws and drills that use electricity and pneumatics must be used because of concerns about discharge and vibrations.	"Piezoelectric discharges can be also released upon exposure to electricity, light and thermal energy. Therefore, repositioning the patient, direct intense light on the crystal, applying an electric current to the device (for example, careless use of electrocautery) may discharge the triggers to ignite the main explosives."
Ahmed 2012	Recognition of the type of explosive ordnance and the rapid provision of information about the nature of the particular hazard associated is essential.	"Agreement with local Explosive Ordnance Disposal team/department is part and parcel of casualty management in these days of widespread terrorism."
Barrow 2023	Emphasizes a multidisciplinary care team to ensure patient safety during initial stabilization and subsequent reconstruction.	"Early connection with psychiatric and/or counseling services is especially appropriate for patients with significant changes to their functional status or appearance."
Bartholomew 2023	Patients should be isolated away from other patients and non-essential hospital staff, including an isolated operating room. Endorses a "5Cs" scenarios with UXO; ensure area is "confirmed," the site is "cleared" and a perimeter is established, then "cordon" off the site, "check" the area, and "control" the situation. Prohibit electrocautery and any other instrument using electricity, heat, or vibration. Minimize repositioning as certain types of fuses can be triggered by reorientation of the devices axis, postural changes, or certain amount of device rotations. If the patient develops cardiac arrest, defibrillation and chest compressions are not recommended.	"In a rural setting, there will be a paucity of resources compared to a metropolitan or military setting. Due to paucity of EOD experts available, getting creative may become important. Primarily, contact local law enforcement. In our case, we reached out to local pyrotechnics experts at fireworks store. Another option would be to look for local munitions' experts, examples being local war reenactment personnel or war museum proprietors."
Clark 1987	Prompt consultation of explosive ordnance disposal specialists to determine if the retained projectile had live explosives. Minimize movement of the patient until the eUXO has been rendered safe.	"It cannot be stressed strongly enough that an autopsy should not be performed in cases involving military munitions without first consulting explosive ordnance disposal personnel."
High 2019	Emphasizes principles of management including early identification of the material, isolation of the patient, and immediate notification and engagement of the EOD personnel. Personal protective equipment for health care personnel should be used. Patient movement should be minimized, and the surgical area should be cordoned off to all but necessary personnel. Avoid the use of defibrillation, cautery, or any device that could initiate an electrical spark or create heat. Even the use of mechanical saws and/or drills could present a risk.	"Proper planning and communication are key in dealing with patients with actual or potential retained UXO. Access to EOD experts is imperative; an open line of communication with EOD personnel along with a departmental plan is ideal."
Howell 2016	Recommends the "5 Cs" approach to ensuring that the area is "confirmed," the site "cleared" then "cordoned" off, "checked" and "controlled." Avoid electrocautery and electromagnetic instruments that could provoke initiation until successful removal of the device. Avoid manipulation of the patient with eUXO to avoid activating any triggering features on the device. Place the patient on a stretcher or gurney and move them to a protected area behind a retaining wall, bunker, sandpit, or open area such as a parking lot. Surgical techniques for eUXO involve minimizing tissue dissection to the absolute necessary with en bloc resection of associated anatomic structures to permit safe UXO management.	"It is imperative that any casualty with suspected UXO be identified early, so that appropriate triage, transport, and management are handled both expeditiously and effectively."
Lein 1999	Avoid electrical equipment, including electrocautery, surgical saws or drills, and blood warmers to avoid activating the fuse mechanism. Plain radiographs are deemed safe and recommended to identify the type of UXO and to define the surgical approach. Avoid other studies (e.g., ultrasonography, computed tomography, magnetic resonance imaging) because of the possible risk of initiation. Intraoperatively, minimize tissue dissection and perform en bloc resection of anatomically involved region to minimize risk of initiation.	"Experience has shown, however, that patients who are not moribund on arrival can safely be triaged into a nonemergent category to allow assembly of all appropriate personnel."
Oh 2018	Assume that all eUXO is "armed" or activated. Ensure participation of EOD staff in mass casualty exercises involving eUXO scenarios to develop procedures. Post up-to-date EOD unit contact information in the surgical facilities administrative area. Avoid repositioning the patient to obtain imaging as this can activate a triggering mechanism and cause eUXO initiation. Remove non-essential personnel from the vicinity of the UXO. Screen all deceased patients for eUXO to prevent initiation during transport of body.	"Prior planning, establishment of a standard operating procedure (SOP), and realistic training are the best ways to prepare for managing these soldiers and avoid ´on the fly´ decision-making."

(*Continued*)

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Table 3. (*Continued*)

Study ID	Recommendations	Quotes
Pengelly 2015	Recommends a "4 Cs" approach of confirm (presence of explosive and alert appropriate authorities), clear (remove non-essential personnel), cordon (isolate area of eUXO), control (establish incident control point).	"Medical staff wear PPE routinely to protect against biological hazard injury caused by sharp objects but are less used to dealing with explosives and as this situation is so unusual it may not be obvious how to continue."
Qin 2014	Not applicable	Not applicable
Spencer 1979	Recommendations include adequate communication (information whether the weapon is live or not if available) and availability of consults from technical experts to assist in determining the type of weapon and danger involved.	"Many [former military bases] were used for training exercises during World War II. Unexploded weapons that could injure the curious and unwary are occasionally found."
Thaut 2018	Recommends trying to remove UXO in the field as opposed to transporting to local civilian hospitals to avoid risk to health personnel. Advises EMS to contact the fire department or nearest EOD capabilities for recommendations before transport. At a health facility, plain films are considered safe but the patient should not be repositioned to obtain films. An EOD team should be on standby in the operating theater to identify and dispose of the ordinance, surgical team should wear protective equipment, operating theater should be cleared of all non-essential personnel, electrocautery should be avoided until UXO is removed.	"Improper management can have catastrophic consequences for the patient, the hospital, and the medical team. The presence of such a device will undeniably cause a heightened state of anxiety, and preparation for such an occurrence can minimize errors."

Abbreviations: EOD – explosive ordnance disposal; eUXO – embedded unexploded ordnance; IED – improved explosive device; UXO – unexploded ordnance

Table 4. Comparison of ICRC and JTS guidelines on management of embedded UXO

ICRC	JTS
Scope and purpose	
Specifically focused on the medical management of patients with eUXO. It is intended for health care professionals who may encounter patients with eUXO.	Designed for military and civilian personnel involved in the identification, handling, and disposal eUXO. It outlines procedures for managing eUXO in various environments, emphasizing the safety of personnel.
Operations and applications	
Largely focused on medical procedures, outlining the steps for safely managing a patient with eUXO. It discusses preoperative considerations, surgical removal techniques, and postoperative care, all while ensuring that the risk of initiation is minimized. It also covers the psychological impact on both the patient and the medical team, providing guidelines for managing stress in such high-risk situations.	Provides a comprehensive approach to eUXO management, including identification, risk assessment, containment, and disposal techniques. It includes detailed procedures for different types of explosive ordnance and various environmental conditions. Emphasis is placed on the use of specialized equipment and the coordination with EOD units for the safe disposal of eUXO.
Primarily applicable in conflict zones or areas where there is a high risk of civilians encountering explosive devices. The guide is particularly useful in humanitarian medical settings, where health care providers may not have immediate access to EOD support.	CPG can be used in both military and civilian contexts, particularly in areas where UXO is prevalent due to past or current conflicts. It is applicable in various scenarios, from active conflict zones to post-conflict demining efforts.
Safety and risk management	
A safety focus on the delicate balance between treating the patient and avoiding eUXO initiation. The guide includes specific recommendations for setting up a safe operating environment and provides protocols for managing potential eUXO initiation during surgery.	Safety is the primary concern, with protocols designed to protect both patient and personnel from accidental initiation of eUXO. The guide emphasizes thorough risk assessments before any action is taken, ensuring that all personnel are aware of the dangers and are properly equipped to manage eUXO.

EOD – explosive ordnance disposal; eUXO – embedded unexploded ordnance; ICRC – International Committee of the Red Cross; JTS – Joint Trauma System; UXO – unexploded ordnance

Numerous barriers to early identification exist, particularly in low-resource settings, including lack of access to subject matter experts. In addition, the nature of the environment (e.g., active conflict or other impermissible environment) may not be amenable to early eUXO detection. In many instances, eUXO identification may be delayed until the patient reaches a health facility or trauma care stabilization point.[31] The delay of eUXO identification until reaching a medical facility effectively transfers the inherent hazard of eUXO to a location with increased risk to a greater number of people, including essential health care personnel, and scarce health care infrastructure. The complexity of these decisions is magnified in low-resource settings where the available health care staff, equipment, and infrastructure may be insufficient to implement existing CPGs. A safe location isolated from surgical facilities in which to manage the patient may not be available in many low-resource settings. Alternative algorithms for eUXO management in environments without established access to EOD teams or higher level of care are required.

Personal safety of prehospital and health facility-based personnel was discussed by all reports included in analysis. Two significant themes include removing all non-essential personnel away from the treatment area and altering or forgoing standard diagnostic and

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treatment modalities that hold potential to initiate eUXO. Multiple reports recommended establishing a pre-incident relationship with EOD assets to utilize their expertise in training medical, standard operating procedure development, and coordination of an eUXO incident. Based on the findings of this scoping review, the authors recommend having an EOD team as a planning partner when developing organizational response plans and treatment modalities utilizing command and control procedures. Adherence to a pre-determined command structure during eUXO incidents is critical to enable organizational leadership to make difficult and complex decisions. Video-assisted or telemedicine-based consultants spanning clinical treatment, EOD, and command and control are possible adjunct solutions if there is sufficient communication infrastructure and preparation of pre-selected experts to participate in the response.[32–34]

Diagnostic and Treatment Modalities

There was also broad concurrence regarding eliminating the use of powered equipment during the resuscitation and treatment of the patient.[18,20,22,24,28] Heat, vibration, or static, caused by medical equipment or movement of the patient has the potential to initiate an item of eUXO. This significantly limits the use of diagnostic (e.g., ultrasound, magnetic resonance imaging, computed axial tomography) and standard medical equipment (e.g., electrocautery). Roentgenography (i.e., fluoroscopy, X-ray) was the only diagnostic imaging modality presented by reports included in this review.[13] Further research is needed regarding the safety of ultrasound due to pressure application of the probe and CT in the setting of eUXO, though the utility of CT may be limited by artifact from the item of eUXO. Additional recommendations emerged including: i) repositioning the patient to obtain optimal imagining is discouraged due to the risk of accidental initiation,[5] and ii) en bloc surgical resection, including associated non-critical anatomic structures as appropriate, is the preferred means for excision and inspection of the device.[23,24] Although this method poses challenging ethical decisions for the treatment team and increases patient morbidity, it reduces the potential for accidental initiation from intraoperative disruption and minimizes risks to the surgical team and critical health care infrastructure.

ICRC[12] versus JTS[13] CPGs

The ICRC and JTS guidelines are foundational and provide valuable information for the management of eUXO incidents (Table 4). These resources are designed for different clinical settings with different resource constraints. Both CPGs are primarily applicable to conflict zones and humanitarian settings where the risk of encountering items of explosive ordnance is high and EOD expertise may not be immediately available. The ICRC CPG strikes a balance between prioritization of patient care and the avoidance of initiation. It provides specific recommendations for setting up a safe surgical environment and provides sample protocols for managing potential eUXO initiation. The ICRC CPG presents risk matrices for likelihood of eUXO initiation based on fuse type and explosive payload. However, in low-resource settings it is unclear that surgical personnel will have the capabilities to identify the type of eUXO with this degree of precision. JTS provides a comprehensive approach to the identification, risk assessment, containment, and disposal of eUXO including detailed procedures for a variety of explosive ordnance types. Emphasis is placed on coordination with EOD teams within existing military structures, but the guidance provided is applicable in scenarios ranging from active conflict zones to post-conflict demining efforts in low- to low-middle income countries.

Conclusion

The emergency management of a patient with eUXO is a complicated clinical and operational problem. The challenges of managing the injuries sustained from these incidents is exacerbated by the inherent risk of initiation and the inability to utilize standard diagnostic and surgical equipment. This review found that safe management of these incidents requires a high degree of preparation that includes pre-incident planning, staff training, resource allocation, and liaising with EOD teams and technical subject matter experts not customarily involved in surgical care. As limited data exist to inform the development of evidence-based CPGs, further research including a T2 Delphi study should be conducted to refine and strengthen guidance on eUXO management in low-resource settings.

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DN, CL, AG, DW conducted the search including screening and extraction.

CL was responsible for descriptive statistics, data management, and data visualization.

EW, HW provided supervision and developed the second draft of the manuscript.

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