A systematic review of military head injuries

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Received 26 November 2015
Revised 14 January 2016
Accepted 18 January 2016
Published Online First 23 February 2016

ABSTRACT

Introduction This commissioned review discusses military head injuries caused by non-ballistic impacts, penetrating fragments and bullets (including parts of bullets) and behind helmet blunt trauma (BHBT).

Method A systematic review of the literature was conducted using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses method. The openly accessible literature was reviewed to investigate military head injuries and their severity.

Results Fifty-four sources were identified that included pertinent openly accessible information relevant to this topic. Limited injury data exist for non-ballistic head injuries for UK forces, although some international data exist for parachutists. The majority of fatal head injuries are due to projectiles penetrating through the face rather than through the area of the head covered by the helmet. Penetrating head injuries are primarily caused by fragments, but helmets are more commonly perforated by high-energy rifle bullets than by fragments. No reports of a BHBT injury have been located in the literature.

Conclusions The description of body segment varies among articles and this makes comparisons among datasets difficult. There is a lack of detail regarding the precise position and severity of injuries, and long-term outcome for casualties. It is demonstrated that wearing military helmets reduces fatalities on and off the battlefield. The risk of BHBT injuries is widely referred to, but evidence of their occurrence is not provided by the authors that describe the risk of BHBT occurring. Further research into the causes and severity of head injuries would be useful for designers of military helmets and other associated personal protective equipment, particularly as advances in materials technology means lighter, thinner and more protective helmets are achievable.

Key messages

- There is a lack of detail in the literature regarding body segment definition, and the precise position and severity of head injuries.
- Minimal injury data exist for non-ballistic head injuries for UK forces, although some international data exist for parachutists.
- Penetrating head injuries are primarily caused by fragments; however, helmets are more commonly perforated by high velocity rifle bullets than by fragments.
- Wearing military helmets reduces fatalities; the majority of fatal head injuries are due to projectiles penetrating the face rather than through a helmeted head.
- No reported incidents of behind helmet blunt trauma (BHBT) injury have been located in the openly accessible literature. The risk of BHBT injuries is widely referred to, but evidence of their occurrence is not provided.

INTRODUCTION

Fragments originating from traditional munitions such as artillery shells, mortars and mines and improvised explosive devices (IEDs) are the major cause of military casualties in general warfare.[1–4] Such injuries include penetrating injuries to the head where the skull is penetrated by a primary or secondary projectile. UK military helmets are primarily designed to provide protection to the brain from fragments, and also provide protection from non-ballistic impacts.[5–9] Non-ballistic impact injuries are those commonly referred to as '*bump*' or '*blunt*' injuries and are caused by blunt or angular threats with relatively low impact energy. A typical modern military helmet comprises of a woven fabric reinforced composite shell, a non-ballistic impact protective liner, suspension and size adjustment systems, comfort pads and a retention system[5 10]; the Mk7 combat helmet, currently worn by UK military personnel, is a typical example of this. Modern solutions for military helmets offer the possibility of protection from bullets (eg, pistol bullets such as 9 mm Luger; 9×19 full metal jacket and rifle bullets such as 7.62×39) and some nations include protection from such threats as a requirement, however, behind helmet blunt trauma (BHBT) is reportedly a concern for several nations.[11–13] BHBT injuries, where the helmet is not perforated, reportedly result from the rapid deformation of helmets caused by ballistic impact—the deformation of the helmet may interact with the head resulting in bone fragments entering the brain.[11–13]

The aim of this systematic review of the open literature was to consider military head injuries caused by non-ballistic impacts, penetrating fragments and bullets (including parts of bullets) and BHBT. It was commissioned by Defence Equipment and Support (DE&S; UK MOD).

METHOD

A systematic review of the open literature was conducted using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method. The Web of Knowledge, Science Direct, Google Scholar and the Ballistic Injury Archive (BIA) were used to identify peer-reviewed journal and conference papers. The BIA was established in 1978 with the terms of reference to '*maintain and update records of published works in the area of war wounds, explosive blast injury and wound*

To cite: Carr DJ, Lewis E, Horsfall I. *J R Army Med Corps* 2017;**163**:13–19.

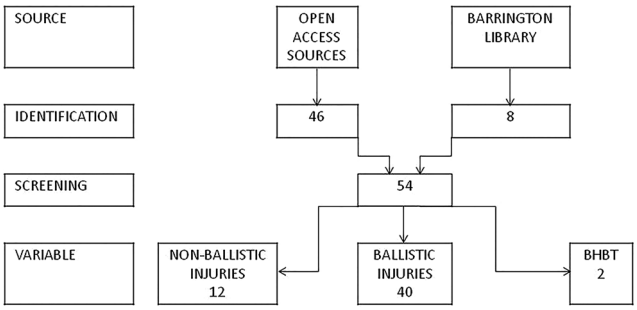

Figure 1 Results of Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) review.

ballistics etcetera'. The collection is available to Service and HM Government Officers and Research Establishments. US government reports were identified using the Defense Technical Information Center, an online depository of DoD and government funded research (http://www.dtic.mil/dtic/). The Barrington Digital Library, which is Cranfield University's Library at The Defence Academy of the United Kingdom (http://barrington.cranfield.ac.uk/), was also searched particularly for MSc and PhD theses of interest. Finally, a full set of the Personal Armour Systems Symposium (PASS) proceedings was hand-searched; PASS started in 1990 as the Ballistic Testing of Personal Armour Symposium (BTPA). In this PRISMA review, proceedings from BTPA1990 to PASS2012 (inclusive) were consulted. At the time of writing, PASS proceedings were only accessible to attendees of the symposia as a digital database of conference paper titles and abstracts did not exist. A full set of proceedings can be accessed via The Barrington Library.

Keywords used for these searches were military, helmet, head, impact, behind helmet blunt trauma, behind armour blunt trauma, BABT, BHBT, non-ballistic, blunt, ballistic, fragment and bullet. Reference lists from articles, reports, theses and conference papers identified were hand-searched to identify additional resources. Only primary sources were used in the literature review.

RESULTS

Fifty-four sources included pertinent information relevant to this systematic review on military head injuries; no other systematic reviews on the subject were identified (Figure 1). Specifically, 40 journal articles, eight conference papers, two reports and two books were identified (four chapters were used from one book).

No incidents of a BHBT injury (since the adoption of composite helmets) were located in the literature. There is significant information in the forensic and medical literature regarding penetrating ballistic head injuries to civilians, however, the

Table 1 Non-ballistic head injuries suffered by military personnel

Location and date	Head injury type (main)	Head injury cause (main)	Comments
UK[16] 1944	Casualty rate 2.1%	Parachuting	Study of 20 777 UK service personnel
UK[17] 1948	Concussion rate 12%	Parachuting	Study of 280 000 UK service personnel from training schools. 0.05% of all jumps resulted in a casualty
USA[18] 1951–1962	Concussion rate 34% Fatality rate 5%	Parachuting	
UK[19] 1964–1970	Head injury rate 0.03%	Parachuting	31 UK military parachutists. 84% of head injuries occurred on landing, amnesia of <1 h occurred in 77% of all cases
Germany[20] 1975–1982	Injury rate 0.25%	Parachuting	Two fatalities: 1×'*skull fracture*'; 1×'*brain injury*'
UK[21] 1987–1991	Fractured skull	Vehicles (36%) Machinery (22%) Falls (30%)	Non-combat UK military personnel hospitalised for >24 h due to head injury Overall injury rate 0.3% Not known if helmet worn
	Concussion	Vehicles (33%) Machinery (31%) Falls (31%)	
	Intracranial injury	Vehicles (27%) Machinery (35%) Falls (34%)	
UK[7] 1978–1994	Fatal injury rate 6%	Parachuting	Study considered 83 hospitalised UK military parachutists
USA[22] 1985–1989	Fatal injury rate 1.4% Concussion rate 57%	Parachuting	277 injured military parachutists
UK[23] 1991 Op GRANBY (Gulf)	11 fatal injuries 60 intracranial injuries 38 concussion 24 open wounds	61 injuries caused by transport 61 41 injuries caused by machinery	153 UK military personnel were hospitalised due to head injuries; 8/11 fatal injuries were attributed to ballistic causes; 65 injured personnel received their injuries when on-duty and 48% of these were recorded as battle casualties. The mean length of hospital stay was 7.75 days
UK[24] 1997	Fractured skull	Helicopter blade impact	Study concluded that wearing the Mk6 helmet saved the life of the injured soldier
Afghanistan[25] 2002	No head injuries	Chinook crash	Study concluded that wearing helmets prevented serious head injuries

AIS, abbreviated injury score; DoD, Department of Defense; KIA, killed in action; MOD, Ministry of Defence; mTBI, mild traumatic brain injury; WIA, wounded in action; WWI; World War I.

Table 2 Ballistic head injuries suffered by military personnel

Location and date	Head injury type (main)	Head injury cause (main)	Comments
WWI[26]	25% head injuries were fatal before helmets introduced 14%–22% head injuries were fatal after helmets introduced	Major cause of injury was fragmentation	The authors concluded that wearing military helmets reduced injuries Proportion of fragment to bullet injuries not reported Data from 1918 reported ~12% head injury rate
New Georgia[27] 1943 and Burma 1944	74 head injuries 30 fatalities due to head injuries (locations: 28 brain, four face and neck)	Head injuries caused in equal numbers by rifle bullets, machine gun bullets (major cause of fatalities 6/25), mortar fragments (9/11), artillery fragments, grenades (9/10)	Study of 369 injured US soldiers The M1 helmet typically not perforated in fatalities suggesting it provided adequate protection. Author commented that an increased area of coverage might be beneficial. The unprotected upper face was the most common point of entry in fatalities
Bougainville Island[28] 1944	20% of wounded and 49% of KIA personnel received at least one wound to the '*head, face, neck*'	55% fatal head wounds were caused by rifle bullets and 77% by machine gun bullets	Study of 1569 Allied casualties (15 February 1944 and 21 April 1944); 10% KIA Cause of injuries was further broken down: mortars (659), rifle bullets (393), grenades (205), machine gun bullets (151) and artillery (151). Those wounded by fragments were more likely to survive. The authors commented on the vulnerability of the face as an impact zone and the success of Japanese marksmanship in targeting the head
Italy[29] WWII	131 head wounds 40% received injuries to head and face	Fragmentation was the major cause of fatality	Study of 983 American service personnel casualties
Korea[30] 1950–1951	1275 wounds occurred to the head (including the face) and neck Data were further broken down into more specific regions, including the skull (i) 64 frontal (54 penetrating), (ii) 48 temporal (47 penetrating), (iii) 30 occipital (23 penetrating) and (iv) 74 parietal (71 penetrating)		Battlefield casualty survey of US personnel (November 1950 to May 1951). Total number of wounds=7773 Fragments caused 92% of casualties and small arms caused 8% of casualties
Korea[30] 1950–1951	375 head injuries 38 face injuries	For '*died of wounds*' personnel, 14/125 suffered brain damage	Study of 1500 KIA United Nations personnel (January 1951)
Korea[30] 1950–1951	76 wounds to the head (15 posterior)		Study of 950 wounds suffered by 286 WIA Turkish Brigade personnel
Cyprus Emergency[31] 1955	108 head injuries (including accidents) 38 fatalities due to head injuries		Study of 491 UK military casualties after State of Emergency declared 26 November 1955. Cause of casualties: bombs (256), bullets (177), mines (40)
Vietnam[32] 1967–1968	1025 fatalities suffered one or more head injury 454 fatalities were caused by single wounds		Study of 2600 US combat fatalities (1967–1968) Author noted that the majority of casualties wore armour and that the unprotected areas of the face and neck were particularly vulnerable particularly when personnel were in the prone position
WWII, Korea and Vietnam[33]	Brain injury fatalities 34%–40% Author suggested that penetrating brain wounds could result in 10%–14% postoperative mortality; if WWI data were included this surgical mortality value for head injuries increased to 40%		Comparison of US Army combat deaths from WWII, Korea and Vietnam. Author suggested that postoperative mortality improvements due to effectiveness of helmet and improved surgical practice. Author recommended that head and neck injuries should be separated in future studies
Belfast[34] 1974	65 fatal head injuries	108 gunshot injuries to the head	Study of 1373 injuries suffered by UK service personnel (1972–1974). Included 236 fatalities (17% of total) 21% of all injuries were caused by bomb blasts or mines and 24% during rioting (no body segment data were provided). Author suggested that the issued flak jacket reduced injuries
Belfast[35] 1971–1974	65 personnel were wounded in the '*head or neck*' 46 fatal head injuries	41 personnel wounded in the head by bullets	Study of 1357 injuries suffered by UK service personnel (1 January 1971–31 December 1974) Of 236 fatalities, 135 were caused by bullets and 81 fatalities were caused by explosive devices

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Table 2 Continued

Location and date	Head injury type (main)	Head injury cause (main)	Comments
Falklands[36] 1982	36 casualties sustained head and neck wounds	One fatal '*gross*' brain damage caused by gunshot	Study of 233 UK casualties operated on by Army Field Surgical Teams during the Falklands War (2 April 1982–14 June 1982). Three fatalities; 38 wounds were caused by bullets, 105 by fragments, 25 by mines and 29 were not reported. Surviving casualties with head injuries were injured by low velocity rather than high velocity projectiles
Lebanon[37] 1982	9% of fatal injuries occurred to the helmeted head; 74% of these occurred to the frontal bones 22% of fatal injuries occurred to the face; the area between the lips and the zygomatic bones was particularly vulnerable receiving 10% of all impacts	7% fatal head injuries caused by fragments 15% of fatal head injuries caused by bullets	Study of 164 Israeli fatalities from the Lebanon War (6 June 1982–20 September 1982). 405 penetrating injuries; 90% occurred to the front of the body The authors suggested increasing the protection offered to the front bones of the cranium and adding a rim to the helmet and facial protection to improve protection from projectiles orientating from overhead
Gulf[2] 1991	Four patients with penetrating head injuries	Fragments	Study of 1053 patients with injuries that occurred during the Gulf War and were treated in a British Field Hospital (20 January 1991–6 March 1991). 63 patients had penetrating injuries (31 British, 29 Iraqi, three Egyptian). 80% of the penetrating injuries were caused by fragments
Gulf[38] 1991	24 personnel suffered a head wound; seven suffered only a head wound. Some further breakdown of injury location was included eye (8), face (7), suboccipital (1), temporal (1), unknown (3) Two soldiers suffered penetrating brain injuries (below helmet trim line: supraorbital (1), subfrontal (1))	95% of personnel were injured by fragments and 5% by bullets	Study of head injuries suffered by US Seventh Corps hospitalised during Operation Desert Storm (20 February 1991–10 March 1991). Total number of injuries 143 (head injuries 17%). The authors suggested that the inservice helmet and body armour provided good protection
Gulf[38] 1991	Further breakdown of location: parietal (8), frontal (6), frontotemporal (1), frontotemporal parietal (1), temporal (1), orbital (1), frontal (1)		Study of 19 penetrating head injuries suffered by Iraqi soldiers. Author noted that there are more penetrations through the vault compared with injured US service personnel as the Iraqis wore no helmets or older metal helmets
Northern Ireland[39] 1970–1984	26 fatalities suffered only head injuries; 122 fatalities suffered combined chest and head injuries (86 suffered fragmentation injuries)	External injuries were primarily caused by fragmentation or impacting a hard surface	Study of blast injuries suffered by 828 UK servicemen in Northern Ireland between 1970 and 1984. Of the 291 personnel killed, 90% wore body armour and 20% wore helmets. The author concluded wearing helmets could save more lives
Somalia[40] 1998–1999	14 fatal head injuries	Five fatal head injuries due to gunshot (in four cases the bullet impacted outside the area of coverage of the helmet, in the fifth case the helmet was not worn)	Study of 125 combat US casualties in Somalia (July 1998–March 1999) 55% of injuries caused by bullets, 31% of injuries caused by fragments. One Ranger sustained a gunshot to the head that penetrated his helmet but did not penetrate his skull; the Ranger suffered scalp laceration, brain contusion and momentary blindness. The authors suggested that incidence of fatal head wounds would have been higher if helmets had not been worn
Bosnia and Herzegovina[41] 1999–2002	19 British head injuries		A retrospective analysis of 1864 casualties admitted to a medical unit in Bosnia and Herzegovina (1 October 1999–30 September 2002) suggested that ~44% were military personnel; 525 casualties were British
Jerusalem[42] 2000–2004		34% of head injuries were caused by secondary fragmentation 16% of head injuries were caused by gunshot	Study of 1500 '*terror-related*' patients admitted to Hadassah Ein-Kerem University Hospital in Jerusalem between 2000 and 2004. 34% of gunshot injuries and 20% of secondary fragmentation injuries were suffered by Israeli soldiers. The mean length of stay in hospital was similar irrespective of causative agent (fragmentation ~14±16 days; gunshot 12±24 days)
Kashmir Valley[43] 1999–2006	23% of combat fatalities due to head injuries		Study of Indian Army fatalities sustained due to combat injuries in the Kashmir Valley (January 1999–December 2006). Of all fatalities, 78% were due to gunshot and 21% due to IEDs

Continued

Table 2 Continued

Location and date	Head injury type (main)	Head injury cause (main)	Comments
Iraq[44] 2003	29 head and neck injuries		Prospective analysis of 294 US casualties admitted to Walter Reed Army Medical Center between 1 March 2003 and 1 July 2003 as a result of Operation Iraqi Freedom A similar proportion of injuries were due to gunshot, blast and shrapnel and blunt or vehicle accidents (39%; 31%; 34%)
Israel[45] 2002	Three injuries to the head (helmeted area)	Two bullets (anterior) One fragments (inferior margin of the occipital)	Study of 149 injuries in 26 fatal incidents for the Israeli Defence Force (30 March 2002–22 April 2002)
Iraq[46] 2003	Seven head injuries admitted to ICU (four open head injuries)		Study of 1429 casualties presenting between 17 March 2003 and 30 April 2003 (Op TELIC) at a Field Hospital 11% of patients were coalition military, the remaining being civilian (54%) and prisoners of war (28%)
Iraq[47] 2003–2004	21 patients suffered a penetrating head injury UK military personnel suffered a penetrating head injury	Gunshot	Study of 1455 personnel treated by the 22 Field Hospital Emergency Department in Iraq between November 2003 and March 2004 during Operation Telic III. Included 1091 British personnel. 61 combat injuries
Afghanistan[48] 2006–2009	215 patients treated by a neurosurgeon		Study of combat injuries suffered by 11 158 patients attending UK Field Hospitals between April 2006 and April 2009 (Op HERRICK 4–9)
Iraq[49] 2004–2007	7123 head, face and neck injuries; 2205 mTBI injury (*'no recorded evidence of intracranial injury, and a loss of consciousness of less than 1 h, or loss of consciousness of unknown duration, or unspecified level of consciousness'*) 1841 face injuries 206 neck injuries		A study of 17 627 injuries suffered by male US personnel involved in 4623 explosions that occurred in Iraq between March 2004 and December 2007 Body armour and helmets were worn in ~90% cases
Afghanistan and Iraq[50] 2006–2007	Personnel with a head injury AIS six accounted for 83% of deaths from head injury (20/24 victims)		Study of 76 UK fatalities from Afghanistan and Iraq during 2006–2007; 51 caused by fragments Injury data were mapped against PPE area of coverage; these results were not made publically available, however, the vulnerability of the face and neck (as opposed to the cranium) was highlighted
Lebanon[51] 2000–2004	76 fatal head injuries (occipital and anterior-temporal vulnerable)	Bullets	76 fatal head injuries suffered by 49 members of the Israeli Defence Forces (2000–2004, 2006, 2009) and caused by bullets were retrospectively reanalysed The authors suggested that hierarchical protection be incorporated into helmets, so that the occipital and anterior-temporal areas (approximately 15% of the skull) are protected to a greater level (eg, bullet-protection) since these areas suffered approximately 50% of all injuries
UK Joint Theatre Trauma Registry[52] 2003–2011	813 penetrating head injury; 336 fatalities	625 fragmentation 188 gunshot	Study of 623 patients from coalition military forces The authors noted that more severe injuries and worse outcomes occurred for gunshot injuries
Iraq and Afghanistan UK Joint Theatre Trauma Registry[53] 2003–2014	33 isolated head injuries 13 head injuries combined with other injuries	61% explosions 39% gunshot	Study of 2985 British military casualties 71 died of wounds (defined as *'Personnel who die as a result of injuries inflicted by hostile action after reaching a UK or coalition ally Medical Treatment Facility (MTF)'*.

AIS, abbreviated injury score; DoD, Department of Defense; ICU, intensive care unit; KIA, killed in action; MOD, Ministry of Defence; mTBI, mild traumatic brain injury; PPE, personal protective equipment; WIA, wounded in action; WWI, World War I.

ammunition used (when described) is typically handgun or shotgun (particularly with reference to suicides). More unusual penetrating head injuries from impalements are also the subject of case studies within the forensics literature,[14 15] but is not reviewed further due to the lack of relevance to military injuries. Data obtained for non-ballistic (Table 1) and ballistic head injuries (Table 2) are summarised.

DISCUSSION

The human skull comprises of 22 bones (usually divided into the cranial and facial bones) and accounts for approximately 9% of the human body. While this is a relatively small percentage, the skull protects the brain and thus understanding the cause and severity of head injuries is vital; such information may inform future research in a number of key areas including, but not limited to, protection and medical interventions.

This article reviews the openly accessible literature regarding non-ballistic, penetrating and BHBT head injuries suffered by military personnel. The risk of BHBT injuries is widely referred to, but there is no evidence of their occurrence in the literature thus they are not discussed further.

Information regarding non-ballistic head injuries that occur to military personnel is limited. An assessment of non-ballistic head injuries during combat appears limited to that conducted for the first Gulf War in 1991; the data suggested a decrease in number and severity of injuries compared with non-combat data and the authors assumed this decrease was due to helmet use during combat scenarios. UK combat helmets have provided non-ballistic impact protection for >30 years; other nations also provide such protection but typically at a lower level compared with British helmets. Some British and international data exists for military parachutists, where it can be assumed that helmets were worn during these events; if so the relatively low injury rates recorded can in part be attributed to suitable helmet design—although training is of course paramount.

There are a number of issues with the openly accessible literature identified and summarised in this systematic review. One of the most fundamental issues of the definition of '*the head*' varies among authors with many not distinguishing between the head, which is typically considered to be the area covered by a combat helmet, and face and neck injuries; calls for this to be rectified date back to 1991.[38] The precise position of the injury and the long-term outcome is rarely given and the use of the words '*injuries*' and '*casualties*' also varies among papers; it is not always clear if the use of these words include fatalities or if, among a group of personnel, more than one injury has occurred.

The nationality of the injured is not always given, and such information might allow some assumptions to be made regarding the wearing (or not) of personal protective equipment (PPE) such as body armour, helmets and eye/face protection and potentially of a cause of injury (particularly when discussing rifle ammunition). The wearing of such PPE is rarely explicitly stated or described and when PPE is discussed there are usually brief comments regarding effectiveness (in the author's opinion) or suggestions for improvements. Data are in different formats, for example, actual numbers and percentages; total numbers are often not provided. The cause of the injuries/fatalities designated as ballistic injuries is typically described as fragments (blast) or bullets; rarely is a full breakdown provided. This forensic aspect of injury would be incredibly useful to designers of PPE. Overall, comparison among the different sources is, therefore, difficult beyond general statements. What is clear is that approximately 20% of penetrating military injuries occur to the head (ie, the skull is penetrated, and therefore, excluding the neck). Considering the last 30 years of conflict these penetrating ballistics injuries account for approximately 40%–50% of combat fatalities.

The data does suggest that ballistic head injuries suffered by military personnel are primarily due to fragmentation (traditional munitions and IEDs). Assuming combat helmets are worn, these injuries will usually affect the face and neck (if not protected), as modern military helmets primarily provide protection from fragments. Ballistic impacts involving bullets (which are more likely to kill) are typically due to impacts to the face and to events that perforate helmets. However, the literature suggests that wearing military helmets reduces fatalities. The anterior of the head and the temporal region are reportedly particularly vulnerable to penetrating injuries.

CONCLUSIONS

The accessible literature regarding non-ballistic and ballistic head injuries suffered by military personnel clearly illustrates that wearing a combat helmet protects the brain, reducing severity of injury and reducing fatalities. Fatal head injuries are primarily due to bullets overmatching helmets or from fragments penetrating through the face. The literature refers to risk from BHBT injuries, but no evidence for such injuries was identified in this review; however, it should be noted that there may be sources of information in restricted-access government reports.

Contributors EL commissioned this review which was conducted by DJC and IH. DJC wrote the manuscript which was commented on by EL and IH.

Funding DE&S (PCE/00040).

Competing interests None declared.

Provenance and peer review Not commissioned; externally peer reviewed.

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