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The Development of Evidence-Based Guidelines to Inform the Extrication of Casualties Trapped in Motor Vehicles following a Collision

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in the Faculty of Health Sciences at the University of Cape Town

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Declaration

I, Tim Nutbeam hereby declare that the work on which this thesis is based is my original work (except where acknowledgements indicate otherwise) and that neither the whole work nor any part of it has been, is being, or is to be submitted for another degree in this or any other university. I authorise the University to reproduce for the purpose of research either the whole or any portion of the contents in any manner whatsoever. I further declare the following:

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1) Nutbeam T, Fenwick R, Smith JE, Bouamra O, Wallis L, Stassen W. A comparison of the demographics, injury patterns and outcome data for patients injured in motor vehicle collisions who are trapped compared to those patients who are not trapped. *Scand J Trauma Resusc Emerg Medicine* **29**, 17 (2021).

2) Nutbeam T, Kehoe A, Fenwick R, Smith JE, Bouamra O, Wallis L, Stassen W. Do entrapment, injuries, outcomes and potential for self-extrication vary with age? A pre-specified analysis of the UK trauma registry (TARN). *Scand J Trauma Resusc Emerg Medicine* **30**, 14 (2022).

3) Nutbeam T, Weekes L, Heidari S, Fenwick R, Bouamra O, Smith JE, Stassen W et al. Sex-disaggregated analysis of the injury patterns, outcome data and trapped status of major trauma patients injured in motor vehicle collisions: a prespecified analysis of the UK trauma registry (TARN). BMJ Open 2022;0:e061076. doi:10.1136/ bmjopen-2022-061076

4) Nutbeam, T. Fenwick R, May B, Stassen W, Smith JE, Wallis L, Dayson M, Shippen J. The role of cervical collars and verbal instructions in minimising spinal movement during self-extrication following a motor vehicle collision - a biomechanical study using healthy volunteers. *Scand J Trauma Resusc Emerg Medicine* **29**, 108 (2021).

5) Nutbeam, T. Fenwick R, May B, Stassen W, Smith JE, Shippen J. Maximum movement and cumulative movement (travel) to inform our understanding of secondary spinal cord injury and its application to collar use in self-extrication. *Scand J Trauma Resusc Emerg Medicine* **30**, 4 (2022).

6) Nutbeam, T. Fenwick R, May B, Stassen W, Smith JE, Bowdler J, Wallis L, Shippen J. Assessing spinal movement during four extrication methods: a biomechanical study using healthy volunteers. *Scand J Trauma Resusc Emerg Medicine* **30**, 7 (2022).

7) Nutbeam, T. Fenwick R, May B, Stassen W, Smith JE, Bowdler J, Wallis L, Shippen J. Comparison of 'chain cabling' and 'roof off' extrication types, a biomechanical study in healthy volunteers. ***Under peer review; Injury***

8) Nutbeam T, Brandling J, Wallis L, Stassen W. Understanding people's experiences of extrication whilst being trapped in motor vehicles: a qualitative interview study. ***Under peer review; BMJ Open***

9) Nutbeam T, Fenwick R, Smith JE, Dayson M, Carlin B, Wilson M, Wallis L, Stassen W. A Delphi Study of Rescue and Clinical Subject Matter Experts on the Extrication of Patients Following a Motor Vehicle Collision *Scand J Trauma Resusc Emerg Med* **30,** 41 (2022). https://doi.org/10.1186/s13049-022-01029-x

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- The Trauma Audit Research Network for supplying data for the three retrospective reviews. Special thanks to Omar Bouamra for his coaching in relation to statistical techniques.
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Abstract

Background

Motor vehicle collisions (MVCs) are a common cause of injury and death throughout the world. Following an MVC some patients will remain in their vehicles due to injury, the potential for injury or physical obstruction. Extrication is the process of removing injured or potentially injured patients from vehicles following a motor-vehicle collision. Current extrication practices are based on the principles of ‘movement minimisation’ with the purpose of minimising the incidence of avoidable secondary spinal injury. Movement minimisation adds time to the process of extrication and may result in an excess morbidity and mortality for patients with time dependent injuries. The current extrication approach has evolved without the application of evidence-based medicine (EBM) principles.

The principles of EBM; consideration of the relevant scientific evidence, patient values and preferences and expert clinical judgement are used as a framework for this thesis.

Aims and Objectives

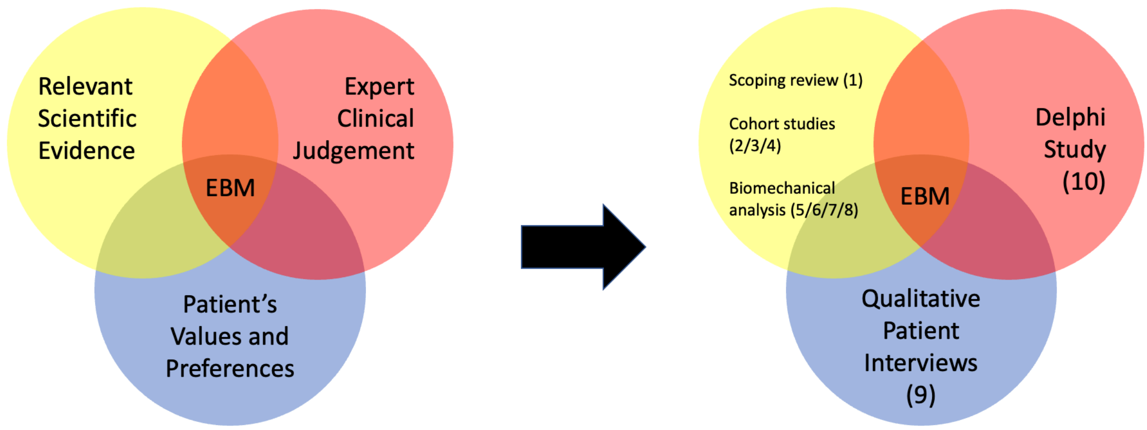
To develop evidence-based guidance for the extrication of patients trapped in motor vehicles by applying EBM principles to this area of practice. This will be achieved through:

- Describing the injury patterns, morbidity and mortality of patients involved in MVCs (trapped and not trapped).
- To analyse the movement associated with and the time taken to deliver across a variety of extrication methods.
- Determining the perceptions of patients who have undergone vehicle extrication and describe their experiences of extrication.
- Developing consensus-based guidelines for extrication.

Methods

To answer these aims and objectives, the principles of EBM were used to plan and deliver a series of studies.

FIGURE 0.1 EVIDENCE BASED MEDICINE AND STUDIES CONTRIBUTING TO THIS RESEARCH



Study 1 is a scoping review using systematic methodology to consider the literature in relation to extrication and related topics from medical, rescue and grey sources. Evidence gaps are highlighted and discussed.

Studies 2,3 and 4 are retrospective cohort studies based on the United Kingdom, national trauma registry. These studies consider the rate of spinal injuries and time-dependent injuries in trapped and not trapped patients. The effect of biological sex (study 3) and ageing (study 4) are analysed and reported separately. Multivariate logistical regression techniques are used to compare the groups and identify and report the excess mortality associated with entrapment.

The relevant scientific evidence section of the EBM framework is completed with four biomechanical studies. Each of these studies are powered using a minimally clinical important difference in cervical spine movement and utilise healthy volunteers across a range of ages and body mass indexes. Inertial motion units are used to capture movements at the cervical and lumbar spine across a range of extrication types.

Study 9 considers patient values and preferences. Semi-structured qualitative interviews are used to report the patient experience of extrication.

Finally in study 10, Delphi consensus techniques were used to consider statements related to extrication derived from studies 1-9. Stakeholder organisations nominated subject matter experts for participation. Following the Delphi process, stakeholders agreed a set of principles based on the consensus statements on which future guidance should be based.

Results

The scoping review demonstrated that the link between reported injuries and deaths associated with MVCs and the evolution of extrication techniques is tenuous.

Study 2 demonstrated that trapped patients have a higher mortality (8.9% vs 5.0%, $p < 0.001$) and more significantly injured (trapped injury severity score (ISS) 18 (interquartile range (IQR) 10–29) vs not trapped 13 (IQR 9–22). The rate of spinal injuries that are likely to influence extrication technique is extremely low (0.7%). In Study 3, female patients are more likely to be trapped than males (female patients (F) 15.8%, male patients (M) 9.4%; p<0.0001). Female patients have a higher incidence of spinal (F 359 (12.5%), M 485 (9.9%); p=0.001) and pelvic (F 420 (14.6%), M 475 (9.7%); p<0.0001) injuries. Male patients have a higher incidence of head (M 1318 (27.0%), F 578 (20.1%)), chest (M 2721 (55.8%), F 1438 (49.9%) and limb injuries M 1744 (35.8%), F 778 (27.0%) all p<0.0001. Study 4 demonstrated that older patients have an excess mortality associated with entrapment (adjusted odds ratio (OR) trapped 30.2 (19.8–46), not trapped 24.2 (20.1–29.2). Older trapped patients have increased but still low rates of spinal injury (80+, 6.6%, mean 6.8%, p=0.345). Injured older patients have a similar potential for self-extrication as younger people (80+, 44.4%, mean 41.4%).

In the biomechanical studies (studies 5-8) when volunteers self-extricated a collar was found to reduce movement at the cervical spine (collar 6.9mm, no-collar 28.3mm, p < 0.001). Self-extrication produced the smallest anterior-posterior movement at the cervical spine (2.6mm), with rapid extrication producing the largest (6.21mm). The differences between self-extrication and all other methods were significant ($p < 0.001$), small non-significant differences existed between roof removal, b-post rip and rapid removal.

Study 9 identified that the main theme across all participants in the patient interviews was the importance of communication; successful communication resulted in a sense of wellbeing and where communication failures occurred this led to distress. The data generated three key sub-themes; ‘on-scene communication’, ‘physical needs’ and ‘emotional needs’. Specific practices were identified that were of use to patients during entrapment and extrication.

In study 10, consensus was reached on 91 statements (89 agree, 2 disagree) covering a broad range of domains related to: extrication terminology, extrication goals and approach, self-extrication, disentanglement, clinical care, immobilisation, patient-focused extrication, emergency services call and triage, and audit and research standards.

Conclusions

This thesis considers current extrication techniques through the ‘lens’ of EBM. By systematically applying EBM principles to this focused area of practice the current approach to extrication is successfully challenged and new, original evidence-based guidance for clinicians and rescuers is offered. The adoption of this fresh approach will reduce extrication times and may reduce morbidity and mortality.

The paradigm of absolute movement minimisation is without a justifiable evidence base; nonetheless it has been historically championed and adopted. Movement minimisation has remained unchallenged for at least four decades, during which time the excess death associated with entrapment has not been investigated nor the paradigm reconsidered.

This thesis adds new knowledge and understanding through retrospective cohort studies and biomechanical work to fill the gaps in the ‘relevant scientific evidence’ component of the EBM triad. These studies demonstrate the low rate of spinal cord injury, the presence of other time dependent injuries and the failure of current, promoted extrication methods to minimise movements.

The patient perspective is now understood, the importance of communication in this environment is reinforced and patient values and preferences are incorporated into new principles that will improve their experience of entrapment and extrication.

Expert clinical and rescuer judgement has facilitated the development of consensus statements. The synthesis of these statements in collaboration with national level stakeholders into new principles will have significant implications for clinicians, rescuers, and patients.

The impact following the adoption of the principles resulting from this thesis on extrication type, time and patient outcomes will be monitored through longitudinal analysis of national level data sets.

This original work will be translated for application in LMIC where a majority of road deaths and injuries occur and where there is the opportunity for the most impact. The successful application of EBM principles to this multidisciplinary area of practice as demonstrated in this thesis will serve as a guide and framework for future work in the relatively unexplored rescuer/ clinical domain.

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Section 1

Introduction and Evidence Review

Chapter 1: Introduction

Background

Motor vehicle collisions (MVCs) are a leading cause of death throughout the world: the World Health Organization (WHO) estimated that MVCs contribute to 1.3 million deaths and 20-50 million injuries globally per annum [1]. The WHO and United Nations (UN) have set ambitious targets to reduce the deaths associated with road trauma; these targets have inspired nations and regions to focus on interventions to reduce the burden of this disease [1,2].

Following an MVC some people will remain in their vehicles. Patients who remain in their vehicles and cannot leave without assistance are considered 'trapped'[3]. Patients can be trapped due to:

i) Their injuries preventing them leaving the vehicle (physical restriction and/or pain),
ii) The transfer of energy to the vehicle causing mechanical or structural changes preventing egress, or,
iii) The patient, bystander or health care provider having concerns in relation to exacerbating a potential injury (particularly spinal) injury preventing movement [4].

Many of these patients will undergo 'extrication', a process by which rescue services (such as Fire and Rescue Services (FRS) in the United Kingdom (UK)) will facilitate their removal from a vehicle [3].

Rescue service extrication techniques have evolved since the 1950's [5–8]. This evolution has been facilitated by the production of faster, more powerful cutting and lifting equipment. However, throughout the last 70 years there has been no change in the fundamental tenet of extrication: that of absolute 'movement minimisation'; the adoption of strategies, techniques and approaches that conceptually lead to minimal spinal movement for the patient being extricated [9,10]. Rescue service guidelines and firefighter manuals inform us that the purpose of movement minimisation is to minimise the frequency and severity of secondary spinal cord injury (Box 1.1) [11,12].

Box 1.1: Quotes illustrating the principle of movement minimisation as adopted by rescue services

"The initial care of a patient with spinal injury will in many cases determine whether that patient regains his normal function or becomes a cripple for the rest of his life" [13]

`The presence of spinal injury must be assumed with any sudden acceleration or deceleration accident'…. `With an unstable fracture or dislocation of the spine, displacement of as little as one millimetre may be enough to compress, pinch or shear the spinal cord" [11]

"The Fire and Rescue Service has killed more people than it has saved through the mishandling of the cervical spine" [14]

The tenet of movement minimisation is well described in FRS training manuals and textbooks which describe 'removing the vehicle from the casualty'. This tenet is captured through FRS extrication training practices such as the avoidance of spilling a full glass of water placed on the dashboard of the vehicle as a surrogate for successful movement minimisation [12].

A closer examination of the movement minimisation concept raises the following considerations:

- Movement minimisation takes time; the longer an extrication takes the longer a patient will remain trapped and the timeline between injury and clinical intervention will similarly extend. This may result in excess morbidity and mortality.
- The utility of current extrication techniques to deliver movement minimisation is unknown, with recent bio-mechanical analysis challenging the assumption that the rescue techniques achieve their central purpose.

- The origins of movement minimisation as a concept and the justification for its adoption as a central tenet of extrication practice are opaque. Importantly there is no discernible evidence of appropriate consideration of available data and the translation of such data into an evidence-based extrication approach.

In short, patients who are trapped following an MVC may do worse than their not trapped counterparts; rescue services are utilising extrication techniques which have not been established from a reputable evidence base, are following a central tenet which may be erroneous and the effectiveness of such techniques to achieve their desired aims is unclear.

This thesis will utilise the principles of evidence-based medicine to explore the status quo of extrication, identify and fill evidence gaps and conclude with an evidence-based alternative to the current situation.

Thesis Aim

To develop evidence-based guidance for the extrication of patients trapped in motor vehicles following a collision.

Objectives

This research aim is broken down into the following objectives:

i) To describe the evidence base for current extrication practices.

ii) To describe the injury patterns, morbidity and mortality of patients involved in MVCs (trapped and not trapped).

iii) To analyse the movement associated with and the time taken to deliver across a variety of extrication methods.

i) To determine the perceptions of patients who have undergone vehicle extrication and describe their experiences.

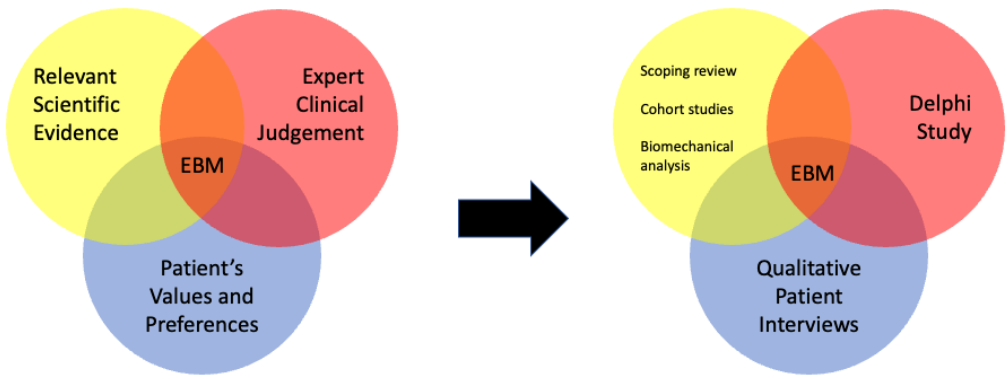
ii) To develop consensus-based guidelines for extrication.

Evidence based medicine and the structure of this research

Evidence-based medicine (EBM) can be defined as a systematic approach to clinical problem solving by the integration of best research evidence with real-world clinical expertise and patient values [15]. It is by the integration of subject matter expertise, best available evidence and patient wishes, perceptions and experience that the 'best' evidence-based solution will be identified.

This research utilises the concept of EBM as a framework for identifying research priorities and addressing knowledge gaps. This research and its relation to EBM can be summarised in the figure below.

FIGURE 1.1 EVIDENCE BASED MEDICINE AND STUDIES CONTRIBUTING TO THIS RESEARCH



This thesis consists of six sections. The sections are introduced below.

Section 1: Introduction and Evidence Review

Section 1 consists of two chapters. Chapter 2 presents a scoping review of the literature in relation to extrication. This chapter considers how the evidence base is applicable to current extrication practice and the gaps in current understanding. This chapter provides important context for the remainder of the thesis and evidences the need and provides the justification for the studies contained in Sections 2-5.

Section 2: Retrospective Cohort Studies

Section 2 consists of three chapters. Each chapter presents an original published retrospective cohort study which identifies, quantifies and reports differences in outcomes and injury patterns between trapped and not trapped patients following an MVC. In Chapter 3, the rates of spinal and time-critical injury in the trapped population are considered and reported, along with excess mortality associated with entrapment. In Chapters 4 and 5, studies specifically consider the effect of biological sex and ageing on outcomes and injury patterns for trapped patients.

Section 3: Biomechanical Studies

Section 3 consists of four chapters, with each chapter presenting an original biomechanical study. Each of the four biomechanical studies assesses the utility of established extrication techniques to deliver movement minimisation. These used a range of healthy volunteers, and the full range of extrication techniques are considered and compared. A novel metric for evaluating cumulative movement is described. The role of cervical collars in minimising movement in self-extrication is considered and analysed in detail.

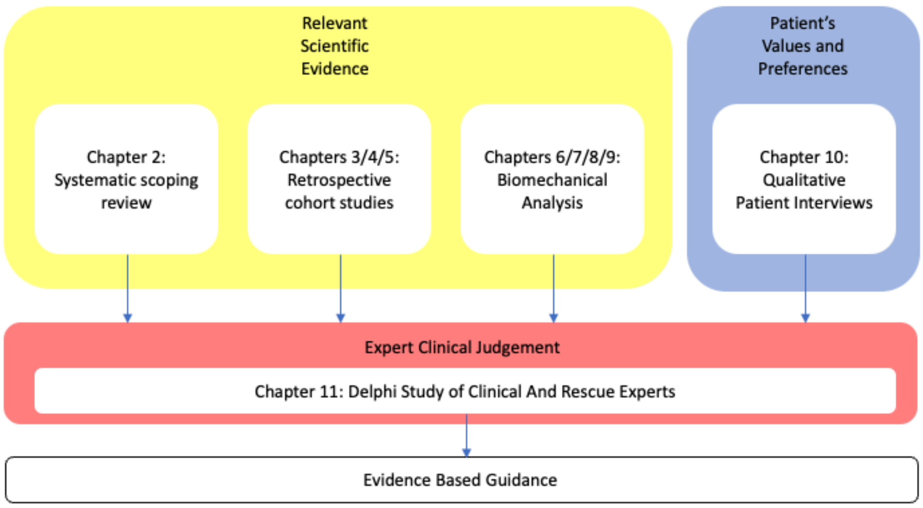
Section 4: Patient Values and Preferences

This section consists of a single chapter (Chapter 10) considering the patient experience of extrication. In this study, patients who had been extricated were interviewed by a qualitative researcher with psychological expertise using semi-structured interviews. A thematic analysis enables the reporting of patient-centred extrication recommendations. This section ensures that patient values and preferences are considered within this EBM approach to the development of new extrication guidance.

Section 5: Expert Clinical Judgement

In Chapter 11 consensus finding techniques are utilised with a multidisciplinary group of prehospital clinical and rescue professionals to translate the available data to practical evidence-based guidance (Figure 1.2).

FIGURE 1.2 THESIS PRESENTATION AND EBM



Section 6: Discussion and Conclusions

The final two chapters of this work will make recommendations on an evidence-based approach to extrication of patients trapped following an MVC; challenges to implementation and translation are addressed and areas for further work identified and prioritised.

Included Papers and Approvals

Nine papers that are integral to this work are included in this thesis. The inclusion of all papers has been approved by the Doctoral Degree Board, contributions to these papers are detailed in Appendix 1.

All studies received approval from the University of Cape Town Faculty of Health Sciences Human Research Ethics Committee and the relevant UK institutions: the Trauma Audit Research Network, Coventry University Ethics Committee and the University of Plymouth Faculty of Health, Faculty Research Ethics Committee. Full details of approvals can be found in Appendix 2.

Chapter 2: Scoping review of the literature

Introduction

The purpose of this chapter is to provide background and the context for the wider thesis. It presents a scoping review of the literature, outlines the evidence that is available and identifies the gaps in the current knowledge base.

Background

Extrication is the process by which injured, or potentially injured casualties are removed from their vehicles following a motor vehicle collision (MVC) [3]. As outlined in Chapter 1, the origin of current extrication techniques and paradigms is largely unknown. An understanding of the historical evidence related to MVCs, injuries and deaths will provide context for accepted, contemporary, extrication practices.

The review objectives can be defined by the following research questions [16]:

- What is the (historical and scientific) context for current extrication approaches as delivered by rescue services?
- What injuries are sustained by patients who are trapped in their motor vehicles and how does this influence extrication practice?
- What are the needs of patients who are trapped following an MVC, how are these met and following extrication where is their care best delivered?

Extrication is a multidisciplinary undertaking; the literature originates from a wide range of disciplines (clinical, rescue, vehicle design and testing). A systematic scoping approach was considered most appropriate for this review due to both the predicted heterogeneity of the literature and the overarching purpose of this review: to identify gaps in the literature which will aid in the planning of future research [17]. This review will describe and give context to the evolution of the current operational and clinical approach to extrication and identify areas where additional knowledge should be prioritised.

For the purposes of this review, extrication is considered as “the rescue and removal of patients from motor vehicles following a collision”. This review does not include other specialist areas such as rescues from water, caves or collapsed buildings. This review excludes the technical detail of rescue practice and the details of specific rescue equipment. This scoping review is reported to Preferred Reporting Items for

Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) guidance [18].

Methods

Search strategy

This is a scoping review; papers and sources were identified through a systematic search strategy based upon PRISMA methodology. The aim was not to identify a single three-part question – but to identify literature that would inform a deep understanding extrication and associated themes (see question statements above).

Development of search terms

The search strategy was developed with professional librarian assistance, trialled, and further refined to ensure that appropriate references and sources were not missed. The final search strategy is summarised in the box below.

BOX 2.1 SEARCH TERMS USED

i)	Extrication OR immobilisation OR intrusion OR roof removal OR side rip OR self-extrication OR chain cabling
ii)	Car OR motor vehicle OR automobile OR vehicle OR road
iii)	Traffic OR accidents OR traffic OR collision
iv)	(MVC OR MVA OR RTA OR RTC) and (collision OR accident)
Search: (i OR ii) AND (iii OR iv)	

The following were searched in August 2021:

Clinical and health care data sources: National Health Services (NHS) available databases using the Healthcare Databases Advanced Search function which includes Medline, EMBASE, CINAHL, EMCare, Healthcare Management Information Consortium (HMIC). From the Cochrane Library we searched the Cochrane Database of Systematic Reviews, Cochrane Central Register of Controlled Trials and Cochrane Clinical Answers. In addition, we searched the Web of Science, Scopus, Health Foundation, Nuffield Trust, PLOS ONE, TRIP, and the Knowledge for Health Care databases.

Trial registries: Clinictrials.gov, WHO International Clinical Trials Registry Platform, EU clinical trials register and the International Standard Randomised Controlled Trial Number ISRCTN registry.

Grey literature sources: The National Grey Literature Collection via the MEDNAR interface, The OAIster® database, The CORE repository, Open Grey, Grey Matters, Google Scholar was used to supplement access to identified papers.

Academic sources: E-theses online service (EThOs) from the British Library, Networked Digital Library of Theses and Dissertation (NDLTD), Open Access Theses and Dissertations (OATD)

Other data sources: safetylit.org, the international transport forum web interface, the national academic of science engineering and medicine and the international research council on biomechanics of injury.

Selection of studies

Following the search, the Endnote interface (EndNote X9.3.3, Clarivate, Philadelphia, PA, 2013) was used to identify and remove duplicate articles. Sources were included for further review which were available in the English language and available online or through library services. The remaining studies were reviewed using their abstract and studies which were not relevant to the research questions excluded. A full-text review allowed further exclusion of articles that were not relevant to the research question. Remaining articles were included and their reference list reviewed to identify further articles for inclusion.

Synthesis

Following exclusions, full text sources were reviewed with reference to the research questions and a broad analysis of the domains identified conducted; articles were grouped into domains, reviewed and included in the narrative discussion.

Results

An initial total of 16,413 documents were identified through the search strategy. This was reduced to 7089 following removal of duplicates. One hundred and seventy papers were identified that were relevant to the research questions. Results are summarised in Figures 2.1 and 2.2.

FIGURE 2.1: STUDIES SCREENED AND INCLUDED (ADAPTED FROM PRISMA)

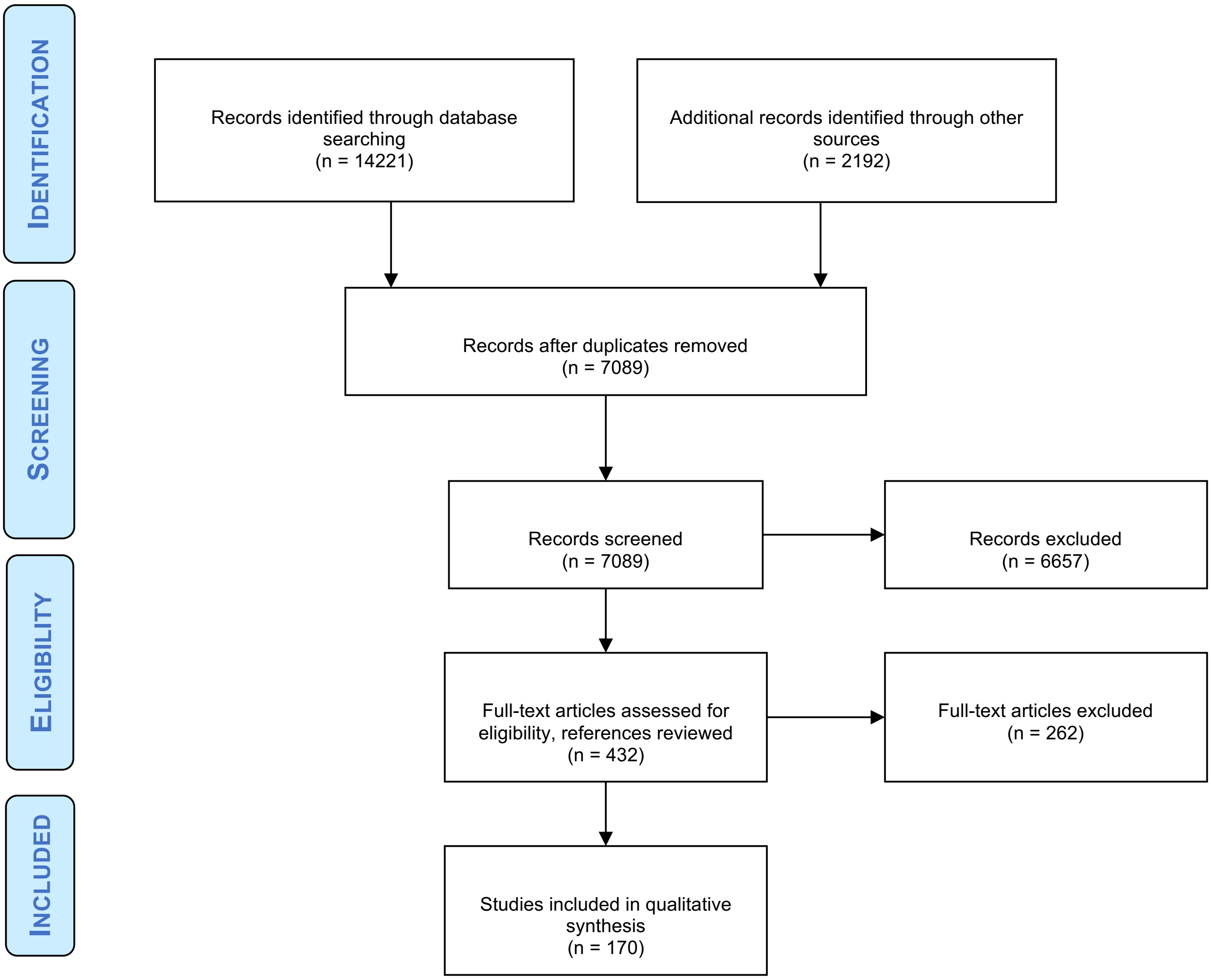
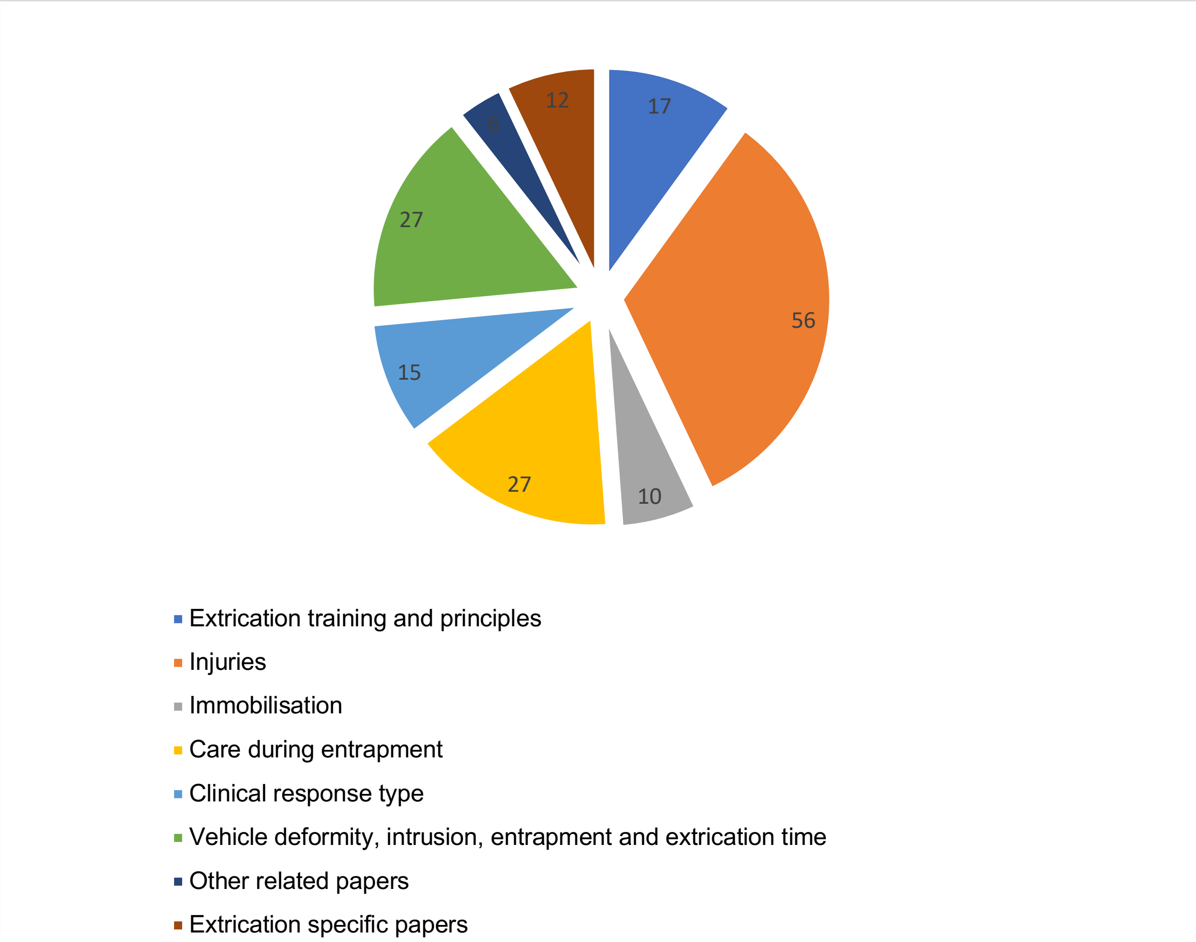


Figure 2.2 Outlines the domains which were identified by full-text review. These are: extrication training and principles, injuries associated with MVC and extrication, immobilisation, care during entrapment, clinical response type and vehicle deformity, intrusion, entrapment and extrication time, other related papers and extrication specific papers.

FIGURE 2.2 DOMAINS IDENTIFIED



Discussion

The scoping review identified studies from a wide range of disciplines and backgrounds. The study types were diverse including computer modelling of accidents and energy transfer, retrospective chart review and database review studies, individual case reports, case series, post-mortem studies, biomechanics, kinematics and mannequin-based studies. There were no randomised controlled trials, no interventional studies of clinical or operational care, and no prospective cohort studies. There were only two unique prospective 'real world' extrication focused analyses [19,20].

Common domains in the literature are explored in the following sections.

Extrication training and principles

The principle of movement minimisation is a key paradigm of contemporary extrication practice [3]. The earliest papers that discussed the priorities to achieve in extrication are from medical journals in the 60's and 70's. These papers identify that patients may have time dependent injuries and state the importance of movement minimisation to prevent avoidable secondary spinal injury following an MVC [5–9,21,22]. The assertions in relation to movement minimisation are made without reference to specific cases, case series or published data. The primacy of movement minimisation during the process of extrication emerges in extrication manuals and guidance aimed at rescue services from the 1970's and onwards [12,23–30]. The manuals and textbooks were unreferenced in respect to the origin of, or justification for the primary focus on spinal injuries above other injuries in the development of extrication paradigms.

Injuries

Early post-mortem studies identify the wide range of injuries from which patients injured in MVC succumbed [31]. Even in these early studies (and before the introduction of modern safety systems) the rate of spinal cord injury and particularly isolated spinal injury (which might justify movement minimisation extrication methods for extrication) was low compared to other injuries; 0.8% of fatalities had a spinal cord injury and 70% had a head injury [31]. With the adoption of seatbelts, the primary injuries and death caused by ejection were minimised with an associated drop in mortality, but new injuries originated: facial fractures from impacting with the internal surfaces of the car and abdominal injuries cause by the belts themselves [32,33].

Much of the literature focuses on injuries in isolation, as opposed to patterns or constellations of injuries. Several papers consider individual cases, case series and mechanism type for a variety of individual injuries including limb [34–37], aortic [38–42], pelvic [43–45] brain [46–49], abdominal [38,50,51] and other body areas and injury types [52–58]. Injured obese patients were identified as having worse outcomes [59].

Spinal injuries

Case reports and retrospective reviews of routinely collected data of severe spinal injury following an MVC featured both adults and children [60–64]. Mezue *et al.* reported failures in prehospital immobilisation and careful handling in patients with subsequently proven spinal cord injury [65]. The authors report that 94.1% of patients in their series were extricated by bystanders and only 36% of the patients had any attempt at immobilisation prior to hospital arrival, the authors report an association between adequate immobilisation and transport and improved function at discharge ($p=0.003$) [65].

Sochor and colleagues identify scene factors which predict the presence of a clinically important spinal injury [66]. In front seat restrained drivers or passengers between 16 and 60 years of age, if the glass in their car was unbroken following an MVC that the rate of clinically important spinal injury was very low. The sensitivity for the GLASS rule was 95.20% (95% CI 91.45–98.95%), specificity was 54.27% (95% CI 53.44–55.09%), and the negative predictive value was 99.92% (95% CI 99.86–99.98%) [66].

Injuries in those who are trapped

Siegel *et al.* compared injuries in patients who required extrication compared to those that did not. They found a higher rate of brain (51% v's 35%, non-significant), lower extremity (58% v's 30%, $p<0.003$) and splenic injuries (22%, v's 10%, $p<0.02$) in patients that required extrication compared to those that did not [67].

Sanson *et al.* report a case series of HEMS delivered critical care interventions on patients who were trapped. They report a high injury load including tension pneumothorax (11.8%), major head injury (39%), and non-compressible haemorrhage (34.7%) [68]. Wilmink reports a case series of entrapment MVCs attended by a UK Helicopter Emergency Medical Services (HEMS) [20], with a high injury load (median ISS 17, range 1-59) in entrapped patients and an associated high mortality (10%). They note that in their case series isolated spinal cord injury did not occur with a majority of patients with severe spinal injury having an associated major head injury affecting their level of consciousness and therefore limiting the efficacy of clinical assessment (36% of all patients had a head or spinal injury) [20]. Westhoff *et al.* consider trapped patients from both passenger vehicles and trucks and report a high degree of severe single system injury (68.7% to the head, 23.5% to the neck, 50.8% to the chest, 43.6% to upper extremities, 15.4% to the abdomen, 16.4% to the pelvis, and 52.9% to lower extremities) and multiple injuries in trapped patients [69].

The literature identified in this scoping review does not provide contemporaneous data that allows us to accurately report the rate of spinal cord injury in entrapped patients. We can conclude that the rate of time dependent injury is high in the those who are entrapped but it is unclear if this is leads to poor outcomes or if entrapment alone might lead to increased morbidity and mortality.

Non-physical injuries

Non-physical injuries are a frequent cause of long-term morbidity and affect the quality of life of those who suffer from them [70]. MVC's are associated with a high rate of post-traumatic stress disorder (PTSD) and other psychological sequelae both in children and adults [71–85]. Mayou's group compared those with multiple injuries following an MVC and those with whiplash injuries alone, they report that in the acute phase (within one month) following the accident that those with multiple injuries were more likely to have an acute stress reaction (41%, comparator not reported); interestingly long-term psychological outcomes did not appear to be correlated with severity of injury [73]. Mosaku K *et al*. performed a complimentary study that identified that clinical factors did not predict long term psychological outcomes [84]. Heron-Delaney conducted a systematic review with the intention of identifying factors that predict PTSD in adult MVC survivors and found that the prevalence of PTSD varied from 6-45% with a "perceived threat to life" being a significant predictor of long term poor psychological recovery [86]. Watts and team found that up to 77% of post MVC victims admitted to hospital were likely to have an "acute psychiatric disorder" with 11-15% seeking or receiving professional counselling [77].

Arnberg and team considered the long-term PTSD outcomes of children following an MVC; they found a high prevalence of stress reactions at nine months following the event (50-69%), with PTSD symptoms still present in 18% of their sample at 20 years [80].

A single paper considered the experience of patients that were trapped (due to spinal cord injury) following an MVC [87]. Sepahvand introduces the concept of "scene shock" in which the injured and untrained bystanders fall into a "state of instability" leading to emotionally driven decisions and subsequent behaviours that lead to desperate, unplanned rescue efforts which may contribute to secondary spinal cord injury [87].

This review confirms that non-physical injuries are common following MVC. Specific data on entrapment or extrication as a risk factor for non-physical injury was not identified. We hypothesise that being trapped would be considered by patients to be a "threat to life" and as such this group may be at higher risk of poor psychological outcomes and long-term symptoms. Importantly, no data was available that recounted the patient experience of entrapment or extrication or considered if changes to this area of practice may improve the patient experience.

Immobilisation

Prehospital services use immobilisation devices to mitigate against movement and ensure or return anatomical normality [88]. Immobilisation can include the application of a femoral traction device, a pelvic sling or the 'triple immobilisation' of a cervical collar, head blocks and a long board or scoop stretcher. Two papers in this review reported pelvic immobilisation techniques and suggest that they may be appropriate for use in entrapment [89,90]. A small number of papers reported methods of paediatric immobilisation using novel techniques or adapting standard prehospital equipment [91–93].

Recent publications challenge the ubiquitous application of cervical collars or the use of spinal boards in the extrication and transportation phase following an MVC [94–97]. These papers, based on expert opinion and an analysis of 'excess imaging' associated with immobilisation suggest alternative approaches including gentle patient handling techniques and self-extrication [94–97].

Immobilisation, particularly the use of cervical collars has been a subject of increasing enquiry and consideration over the last 15 years [98–100]. Authors have challenged the harm / benefit of collar application, particularly in conscious trauma patients [100]. The use of such immobilisation devices specifically in the context of entrapment and extrication is discussed later in this review.

Care during entrapment

Papers were identified that related to the delivery of patient care, minimisation of patient harm or improvement of patient experience during entrapment. No papers were identified which included any description of patient experience or collection of patient generated data (e.g. pain scores).

Single case studies were presented which identify pain and the potential for hypothermia as issues that benefit from mitigation whilst the patient remains trapped [101–104]. A series of four cases supported by a literature review identify that ketamine is well suited for meeting the analgesic needs of a trapped patient [105]. Further papers presented general principles and opinion on pain management options [106,107].

A surprisingly large number of mannequin-based studies evaluated the use of a wide variety of laryngoscopes or supraglottic airway devices for the placement of endotracheal tubes in entrapped mannequins in various positions [108–122]. Individual case studies and small case series supported the use of supraglottic airway devices in extremis [123–125]. A single retrospective chart review of airway management published as an abstract recognised the challenges of intubation in the entrapped patient [126].

The literature in this area is limited to a single case series, expert opinion and mannequin studies looking exclusively at airway management. Literature was not identified that defined patient's clinical needs and priorities for the management during the entrapment and extrication phase.

Clinical response type

The utility of bystanders at the scene of an MVC was considered by several authors. Thierbach *et al.* identified that bystanders were more likely to help with those with moderate injuries than patients with severe injuries and advocated for more advanced widely available bystander training [127]. Heightman and Bhalla discuss the potential utility of bystander care to reduce mortality and morbidity, especially with those with specific training, kit and authorisation [128,129]. Bhalla reflects on the potential medico-legal culpability for bystanders in providing immediate care and how this might be overcome by training and authorisation to act [128,129].

Two studies from the 1990's identified that entrapment was associated with severe injuries, and this resulted in complex patient care needs which were often unmet [130,131]. Many papers advocated for physician attendance at scene for entrapment trauma [132–138]. A single prospective cohort study considering all mechanisms of major trauma found no survival benefit when a physician was present (OR of 1.16 (95% confidence interval = 0.97 to 1.40, p = 0.11).

Byrne *et al.* report that longer response times were associated with higher rates of mortality [139], whilst Gauss and team noted the association between prolonged prehospital time and poor patient outcomes [140].

Patients who are trapped have on average longer prehospital timelines and as such may have an excess mortality for this reason alone [141]. The benefits and potential harms of bystanders to patients and the ideal clinical response model cannot be surmised from the literature available to this review.

Vehicle deformity, intrusion, entrapment and extrication time

These papers considered patient and incident-based factors which predicted (or failed to predict) mortality, injury or the need for trauma centre care. The papers offered different perspectives as to the utility of incident-based factors both in isolation and combined with injury, physiological or patient demographic factors.

The factors of interest to this review are the association between vehicle structural deformity (external), intrusion into the passenger compartment and the requirement for the extrication of a patient. These factors are important to our question of the inter-relation of patient injury and their ability to self-extricate.

Three papers considered the accuracy of the data recorded by both paramedics and emergency physicians in terms of scene characteristics (such as need for extrication). Poor completion of prehospital records and poor correlation between findings at scene and subsequent analysis led to both under and over triage (EMS record accuracy median 28.5%, range 0-100%) [142–144].

<u>Deformity</u>

External vehicle deformity was found to be important when combined with intrusion in the absence of air bags (OR 5.2, 95% CI 2.525–10.780) [145]. Deformity was also important in predicting mortality in older patients (differences in mortality were associated with age (OR 6.92,95% CI 1.2-38.9) and a high vehicle deformity (OR 3.28, 95%C1 1.5-6.8)[146].

Intrusion:

Studies reached different conclusions when considering intrusion alone as a predictor of injury, mortality or trauma system utilisation [147,148]. One paper identified supported the utilisation of intrusion alone in frontal collisions as an indicator of major trauma and as such should feature on major trauma triage tools [149]. A paper from 1996 reported the utility of intrusion of >24 inches as a triage criterion but found other mechanistic criteria were not useful [150]. Davidson *et al.* found that intrusion of more than 12 inches were useful in predicting trauma centre utilisation over and above physiological criteria; they found mechanistic criteria particularly useful in older patients without physiological derangement. Intrusion of greater than 12 inches had a PPV of 10.4% (95% CI, 9.5-11.3) to predict severe injury; steering wheel collapse had a PPV of 25.7% (95% CI, 23.0-28.4%) for the same outcome [151].

More recent reviews did not support intrusion as a stand-alone predictor of injury, and instead suggest that patients triaged on intrusion alone had low Injury Severity Score (ISS) and a high discharge rate (ISS was 5 (1.75, 10.25) and 39.5% were discharged from the Emergency Department (ED)) [152,153]. Simon *et al.* recommend that if certain mechanistic features were present and no evidence of physiological disturbance then an initial clinical review of the patient should occur and then upgrade to a trauma team if required [154]

The combination of intrusion and entrapment, which are often inter-related, was identified as useful for predicting patient mortality. When adjusted for age and sex, the following mechanism of injury (MOI) were associated with mortality: passenger space intrusion (OR 1.74; CI 1.18, 2.57), extrication (OR 2.16, CI 1.14, 4.04), ejection (OR 8.33; CI 4.68, 14.83) and occupant fatality (OR 2.28; CI 0.50, 10.40) [155].

Entrapment and extrication

Many groups identified that entrapment, particularly when associated with prolonged or difficult extrication (typically defined as > 20 minutes) was a useful predictor of injury (multivariate OR 2.5, 1.1–6.0, p=0.04), and was a more sensitive and specific criterion for trauma centre utilisation than other mechanistic features [10,156–162].

This finding was not universal with two authors recommending that the need for extrication in isolation should be removed from triage guidance as it led to considerable over-triage [163,164].

There were no studies concerning vehicle deformity or extrication which included children. However, intrusion was found to be associated with increased injury in children, with a direct relationship between the amount of intrusion and associated injuries (4.0% increase in AIS3+ injuries for each cm of intrusion (95% CI = 2.7-5.2%) [165–167].

<u>Other related papers</u>

Ryb *et al.* suggested that patient mobility post collision was more useful than mechanistic factors in triaging patients to an appropriate facility; self-extrication under-triaged by 0.4% as a predictor of death[168]. Schulman and colleagues developed a composite "Scenescore" consisting of weighted values for age, collision type, impact location, airbag deployment, steering wheel deformity, intrusion, and restraint use; they suggest a score of 8 offers optimal performance (sensitivity 76%, specificity 46%) to assist with triage decisions [169]. Technological solutions were also suggested utilising automatic crash notification or vehicle telemetry to predict injuries and inform response [170–172].

As might be expected the conclusions and recommendations varied with the era of analysis and publication. This may be in part to the increased safety of vehicle systems, the development of vehicles in terms of crumple zones, changes in the way patients were considered trapped or needed extrication and the individual capability and acceptable over-triage rates of the system under consideration.

Extrication specific papers:

Nutbeam *et al.* prospectively collected data at the scene of entrapment MVC, then used this to report factors that predict the need for extrication, the factors which affect this time and the number of extrications in which physical or actual entrapment occurs (10%) [19,141,173]. This low rate of physical entrapment (10% of all extrications), the time taken for extrication (median 30 minutes) and the increased mortality seen with both entrapment and increasing time between injury and arrival at hospital demonstrates the importance of the entrapped patient as an area where increased knowledge and decreasing the rate and time of entrapment may lead to improved patient outcomes.

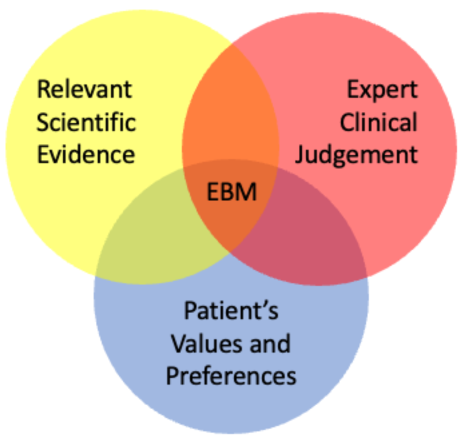
There were very few papers that considered the effect of extrication technique on entrapment time or patient outcomes. Lars and Fattah both demonstrate the speed of chain cabling type techniques which are used in Scandinavian countries but not frequently used elsewhere compared to more traditional techniques in experimental conditions [174,175].

There are a number of papers that report bio-mechanical analysis using various methodologies and a range of extrication types. Bucher *et al.* found that utilising a KED (Kendrick extrication device) resulted in less spinal movement in patients with a normal body mass index (BMI) but increased spinal movement in obese patients [176]. Shafer *et al.* performed a pilot study which concluded that allowing an individual to exit a car under their own volition (self-extrication) with a cervical collar in place may result in the least amount of motion compared to exiting with paramedic assistance [177]. These findings were reinforced by Engsverg, Gabrieli, Haske and Dixon and their respective teams across a number of extrication methods using a variety of biomechanical methods and outcome measures [178–182].

Where are the gaps?

Considering the large number of patients whose clinical care, timeline to hospital and patient experience may have been adversely affected by their trapped status, there is little focused literature which allows an understanding of key areas of this phenomenon which would enable an EBM approach to the development of evidence-based extrication guidance.

Figure 2.3 The EBM Triad



Areas of 'relevant scientific evidence' where data is not available or not sufficient includes the difference in injury patterns between trapped and not trapped patients, the difference in outcome between trapped and not trapped patients, the efficacy of extrication techniques to minimise movement and their clinical or outcome implications. There is not currently evidence that enables us to understand ‘patient values and preferences’; we do not have data which supports an understanding of the patient experience of extrication and how this may be improved. Despite a large number of case reports and papers from single or small groups of experts there is no coherent, consensus “expert clinical judgement’ which bridges the rescuer-clinician divide in the current literature. The absence of multidisciplinary guidance based on the best available evidence demonstrates another notable gap in relation to this important patient group.

Our understanding of these important areas of research could be improved by targeted studies analysing high-quality data sources which allow comparison of injuries, injury patterns and outcomes between trapped and not-trapped patients following an MVC. Such analyses will be enhanced by reporting the frequency of isolated spinal injuries that may be exacerbated by movement and time-critical injuries such as significant head injuries. These analyses will contextualise the risk of secondary spinal injury, the risks of patient deterioration whilst trapped and help us to understand the potential for self-extrication. Sub-analyses which allow comparisons between patients of different ages, sex and body habitus will further inform decision making in this area.

Current biomechanical data of extrications are limited to small numbers of extrications across a small pool of healthy volunteers. Where possible, real-world data should be collected to inform our understanding of the performance of currently deployed extrication techniques. If real-world data collection is not possible then researchers should deliver adequately powered studies which consider all extrication types across a range of people.

Good evidence-based medicine requires the consideration of patient values and preferences [15]. The absence of the patient voice from the current evidence base is notable and rectifying this should be a target for future research. Patient surveys and interviews will assist in capturing the patient perspective and routinely collected data in this area should include patient experience. Patient priorities should be identified, and patient representatives should be engaged in the development of guidance for the care of patients whilst they are entrapped and subsequently extricated.

Solutions for the evidence gaps identified above will enable the development of much needed evidence-based multidisciplinary guidance through consensus processes.

Limitations of this scoping review

We aimed for a comprehensive search strategy; however, it may have missed studies that were important to our defined questions. Steps were taken to keep the inclusion criteria broad and included a large number of grey literature sources; which in turn required the review of a large number of papers. By defining questions in advance, we attempted to produce a decision-making process which was predictable and reproducible, but this was not confirmed through any verification process. A single researcher applied the questions and made decisions regarding inclusion and exclusion criteria, which may have improved the reliability of these decisions but threatens the reproducibility if repeated by another person or team.

The nature of the scoping review does not require a formal risk of bias assessment. The broad nature of the review does not allow for the comprehensive synthesis of all domains, nor does it provide the specificity to identify immediate recommendations to improve extrication practice.

Conclusions

There is a paucity of published evidence to support the current approach to extrication of entrapped patients following an MVC. Focused studies identifying in detail the injures and their sequelae associated with entrapment, the biomechanics of current techniques and ensuring that the patient perspective is captured will enable the development of much needed evidence based multidisciplinary guidance.

Discussion and additional considerations, Section 1

From the scoping review presented, it is clear that the current practice of absolute movement minimisation is not rooted in strong scientific evidence, while current literature does not take all aspects of the EBM triad into account. So, if not founded in data and evidence, what are the origins of current practice? Attempts were made to identify the original data and source for the quotes from contemporaneous literature that support contemporary approaches to extrication:

"The initial care of a patient with spinal injury will in many cases determine whether that patient regains his normal function or becomes a cripple for the rest of his life", Nancy Caroline, 1979 [13]

This quote comes from the first edition of Nancy Caroline's "Emergency Care in the Streets" [13]. The first and all subsequent editions of this textbook were reviewed and the chapter references scrutinised. The original source of this quotation could not be traced further than the first edition of the text. None of the references of any of the editions provide a source reference which describes the progression of primary cord injury to secondary cord injury.

Caroline was extremely influential in Emergency Medical Services (EMS) education and enablement, founding several ambulance services and being a proponent of paramedic training and development. In the United States (US) where Caroline worked, rescue systems and clinical systems are intrinsically linked with paramedics working alongside and as firefighters (and vice versa). It may have been through these links that Caroline's work translated into the current extrication paradigm.

`The presence of spinal injury must be assumed with any sudden acceleration or deceleration accident'…. `With an unstable fracture or dislocation of the spine, displacement of as little as one millimetre may be enough to compress, pinch or shear the spinal cord" [11]

This quote is unreferenced in its original source. It is however very similar to text found in early editions of the Advanced Trauma Life Support course (ATLS) and textbooks from the American Academy of Orthopaedic Surgeons (AAOS) [183,184]. It is unclear from reading serial versions of FRS manuals the process by which movement minimisation became a focus within extrication techniques and casualty care. Broadly speaking, prior to 1980, spinal injuries are considered within casualty care but are not given predominant attention. Post-1980, spinal injuries are given much great prominence in casualty care and as a result extrication technique.

“The Fire and Rescue Service has killed more people than it has saved through the mishandling of the cervical spine” [14].

This quote is from the teaching of Roger Snook at the National Fire and Rescue Training Centre (UK) from the early 1990’s [14] – it was described as the first slide used in his introduction to casualty care of the trainee FRS personnel and as such is likely to have been impactful. Snook had a keen interest in extrication; this was the subject of his MD thesis and he published on the subject of medical care at the scene of accidents [5,9,185]. Snook’s publications make reference to cervical injury and suggest methods to minimise movement to prevent secondary injury. However, similar to the FRS manuals and EMS textbooks of that era, spinal injury is considered alongside other injuries associated with MVC, with pragmatic solutions suggested to minimise time of entrapment: “*Such situations represent probably the most demanding of all that the emergency services have to face. Assessment, supportive measures, techniques of extrication and handling all have to be combined and balanced against the effect of the time factor”* [185].

It is unclear what influenced the increased focus on spinal injury and subsequent adoption of movement minimisation techniques by Snook and others. Attempts to contact authors from this time (including Snook, ATLS and AAOS) have been unsuccessful.

Key messages: Section 1

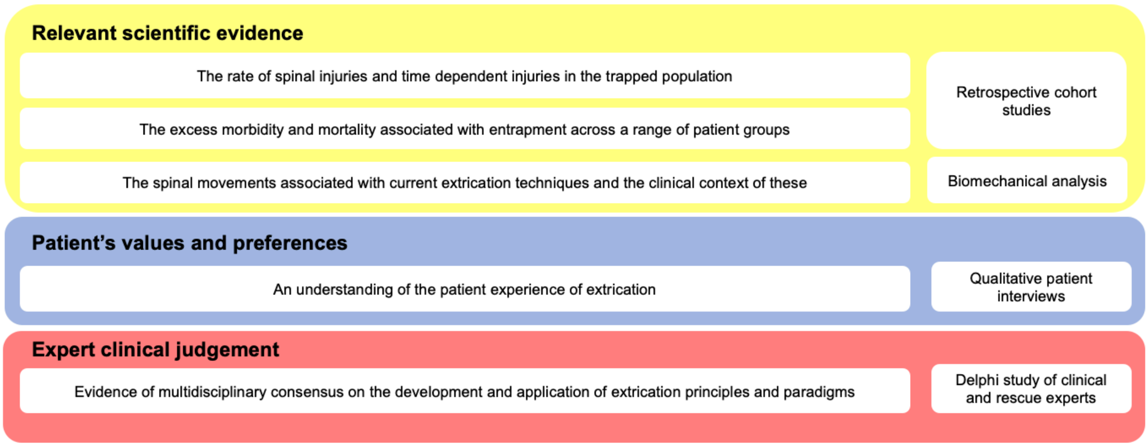
- Current extrication practices and paradigms are not grounded in evidence
- References to a high rate of spinal injuries caused by rescuer handling are 'zombie' statistics without an identifiable origin

Evidential gaps include:

- The rate of spinal injuries and time dependent injuries in the trapped population.
- The excess morbidity and mortality associated with entrapment across a range of patient groups
- The spinal movements associated with current extrication techniques and a clinical context for these (secondary spinal injury)
- An understanding of the patient experience of extrication
- Evidence of multidisciplinary consensus on the development and application of extrication principles and paradigms

Figure 2.4 outlines how this thesis will address these evidence gaps using the triad of EBM principles.

FIGURE 2.4 EVIDENCE GAPS AND HOW THESE WILL BE ADDRESSED IN THIS THESIS



Section 2

Retrospective Cohort Studies

Section 2 incorporates three retrospective cohort studies which identify, quantify and report differences in outcomes and injury patterns between trapped and not trapped patients following an MVC. The rate of spinal and time critical injury in the trapped population is considered and reported. Excess mortality associated with entrapment is analysed and reported. Additional analyses specifically consider the effect of ageing and biological sex on outcomes and injury patterns for trapped patients.

This section consists of the following sub-sections:

- Section introduction
- Chapter 3: Nutbeam T, Fenwick R, Smith JE, Bouamra O, Wallis L, Stassen W. A comparison of the demographics, injury patterns and outcome data for patients injured in motor vehicle collisions who are trapped compared to those patients who are not trapped. *Scand J Trauma Resusc Emerg Medicine* **29**, 17 (2021).

  Chapter 4: Nutbeam T, Weekes L, Heidari S, Fenwick R, Bouamra O, Smith JE, Stassen W et al. Sex-disaggregated analysis of the injury patterns, outcome data and trapped status of major trauma patients injured in motor vehicle collisions: a prespecified analysis of the UK trauma registry (TARN). BMJ Open 2022;0:e061076. doi:10.1136/ bmjopen-2022-061076

  Chapter 5: Nutbeam T, Kehoe A, Fenwick R, Smith JE, Bouamra O, Wallis L, Stassen W. Do entrapment, injuries, outcomes and potential for self-extrication vary with age? A pre-specified analysis of the UK trauma registry (TARN). *Scand J Trauma Resusc Emerg Medicine* **30**, 14 (2022).
- Section discussion
- Key messages

Section introduction

Aims and purpose

Section 2 addresses the knowledge gap in relation to our understanding of the injuries and outcomes of patients who are trapped following an MVC. An understanding of these injuries is essential in understanding the applicability of current extrication paradigms and provides context and an understanding of the type and time sensitivity of injuries associated with entrapment.

Not all patients are the same. Patient related factors such as age, co-morbidities, size, body mass index (BMI), frailty, sex and gender may all influence the transfer, distribution and consequences of energy transfer following an MVC. Such factors may affect the efficacy of vehicle safety systems, the injuries sustained, the subsequent ability or otherwise for a patient to self-extricate and the applicability of extrication techniques and paradigms.

TARN as a data source

The three studies presented in this section rely on data collected by the Trauma Audit and Research Network (TARN), a UK based trauma registry. TARN was established in 1990, with mandatory reporting of major trauma to TARN by all hospitals assessing and treating patients with acute major trauma in England and Wales beginning in 2012. TARN collects data from adult patients in England and Wales who meet their inclusion criteria (Appendix 2).

TARN is a rich source of data enabling access to and analysis of patient demographics, comorbidities, injuries, treatments and process and outcomes. TARN do not collect body mass, BMI, height or frailty. In motor-vehicle collision patients TARN collect a single datapoint related to extrication: 'trapped' / 'not trapped' which the individual hospital site TARN data team extract where possible from the prehospital clinical records. TARN does not collect the type of entrapment (such as physical or medical entrapment), the route of extrication or the time that a patient remained trapped.

TARN has been granted section 251 permissions by a Confidentiality Advisory Group appointed by the Health Research Authority [186]. Section 251 of the NHS Act 2006 allows the common law duty of confidentiality to be set aside for the collection and use of patient identifiable information. Approval is only given where the work aims to improve patient care and is in the public interest.

The work we do at The Trauma Audit & Research Network has been approved and our approval is reviewed annually. It is reviewed by the Confidentiality Advisory Group, within the Health Research Authority. Part of the approval process is focused on the security of the information collected.

Section 251 also allows for the processing of the data for the purposes of *'the public interest, scientific or historical research purposes or statistical purposes'*, providing that this is '*proportionate to the aim pursued, respect the essence of the right to data protection and provide for the suitable and specific measures to safeguard the fundamental rights and interests of the data subject*'.

As such TARN data analyses that are conducted using anonymised data (such as those presented in this section) do not require additional individual UK ethical approval. The analyses included in this section were approved by the University of Cape Town (180/2021).

Spinal injuries and time sensitive injuries

When considering extrication an understanding of the frequency of a range of spinal injuries, body regions majorly injured and known time-sensitive injuries all add important context. TARN details the presence, level and classification of any traumatic vertebral fracture, vertebral dislocation disc injury, nerve root injury or cord injury. TARN specifically excludes sprains, strains and isolated ligamentous injuries. As such, interrogation of the TARN dataset provides sufficient detail to describe with accuracy the spinal injuries in each patient / patient group considered.

Consensus processes have been used to define time lifesaving interventions for time dependent injuries [187]. The TARN dataset has been used to develop and validate triage tools to identify time dependent injuries [188–190]. In this section a combination of specific accepted time dependent injuries (e.g. tension pneumothorax), interventions (e.g. intubation, tranexamic acid and blood product resuscitation) along with the Abbreviated Injury Scale (AIS), Injury Severity Score (ISS) and physiological markers are used to compare trapped and not trapped patients.

Statistical considerations

In this section multiple comparisons are made between trapped and not trapped patients. To avoid false positives researchers are advised to consider adjustment of p-values using an accepted method (such as the Bonferroni calculation) to revising the p-value thresholds [191,192]. In consideration of this in this section a p-value of <0.01 is considered statistically significant across the papers presented.

The 'Ws' statistic is used in this section to compare outcomes between groups. TARN has developed an outcome prediction model using age, gender and their interaction and ISS, GCS and Charlson comorbidity index as independent predictors. This allows calculation of a Probability of Survival for every patient. This is used to build up a Performance Indicator, the W statistic (Ws) which compares groups of patients or institutions. Ws is a directly standardised survival rate derived from a difference between observed and expected number of survivors per 100 patients. A positive value of Ws indicates that the institution has more survivors than predicted, and so its performance is above (lower mortality) the standard in the prediction database. A negative value of Ws indicates that the institution has less survivors than predicted and so its performance is below the standard in the prediction database. Using this methodology, the Probability of Survival is calculated for each group and compared between the groups. In addition to the W statistic unadjusted odds ratios (OR) for the trapped and non-trapped groups are reported.

The next chapters which make up the remainders of this section consist of three original papers which are reproduced in full but formatted to provide consistency throughout this thesis. This section ends with a discussion of the contributory chapters and relates their findings and outcomes to the thesis as a whole.

Chapter 3: A comparison of the demographics, injury patterns and outcome data for patients injured in motor vehicle collisions who are trapped compared to those patients who are not trapped

Declaration from author and co-authors

The following co-authors contributed to the publication: Fenwick R, Smith JE, Bouamra O, Wallis L, Stassen W.

Contributions of the authors were as follows: TN, RF, JS, LW and WS contributed to the conception and study design, analysis and interpretation of data, drafting and revising the manuscript. OB contributed to the analysis and interpretation of the data and critically revised the manuscript. All authors read and approved the final manuscript.

The extent of contributions from each person are as follows:

- TN: 50%
- JS: 10%
- LW: 5%
- RF: 10%
- OB: 10%
- WS: 15%

Given the large number of co-authors, the principal investigator and the supervisor hereby sign for approval on behalf of the group, in accordance with the UCT Doctoral Degrees Board guideline titled, “GUIDELINES FOR THE INCLUSION OF PUBLICATIONS IN A DOCTORAL THESIS.”

25 July 2022

Tim Nutbeam — Date

25 July 2022

Willem Stassen — Date

Abstract

Background

Motor vehicle collisions (MVCs) are a common cause of major trauma and death. Following an MVC, up to 40% of patients will be trapped in their vehicle. Extrication methods are focused on the prevention of secondary spinal injury through movement minimisation and mitigation. This approach is time consuming and patients may have time-critical injuries. The purpose of this study is to describe the outcomes and injuries of those trapped following an MVC: this will help guide meaningful patient-focused interventions and future extrication strategies.

Methods

We undertook a retrospective database study using the Trauma Audit and Research Network database. Patients were included if they were admitted to an English hospital following an MVC from 2012-2018. Patients were excluded when their outcomes were not known or if they were secondary transfers.

Results

This analysis identified 426,135 cases of which 63,625 patients were included: 6983 trapped and 56,642 not trapped. Trapped patients had a higher mortality (8.9% vs 5.0%, $p<0.001$). Spinal cord injuries were rare (0.29% of all extrications) but frequently (50.1%) associated with other severe injuries. Spinal cord injuries were more common in patients who were not trapped ($p<0.001$).

Injury Severity Score (ISS) was higher in the trapped group 18 (IQR 10-29) vs 13 (IQR 9-22). Trapped patients had more deranged physiology with lower blood pressures, lower oxygen saturations and lower Glasgow comas Scale, GCS (all $p<0.001$). Trapped patients had more significant injuries of the head chest, abdomen and spine (all $p<0.001$) and an increased rate of pelvic injures with significant blood loss, blood loss from other areas or tension pneumothorax (all $p<0.001$).

Conclusion

Trapped patients are more likely to die than those who are not trapped. The frequency of spinal cord injuries is low, accounting for <0.3% of all patients extricated. Patients who are trapped are more likely to have time-critical injuries requiring intervention. Extrication takes time and when considering the frequency, type and severity of

injuries reported here, the benefit of movement minimisation may be outweighed by the additional time taken. Improved extrication strategies should be developed which are evidence-based and allow for the expedient management of other life-threatening injuries.

Key words:

Extrication, Road Traffic Collision, Spinal injury, Cervical collars, Pre-hospital care

Background

Motor Vehicle Collisions (MVCs) are the second most common cause of major trauma in the United Kingdom (UK) [193]. Following an MVC, patients within the car prior to the incident occurring can be ejected from the car, leave the car with or without assistance, or may remain in the vehicle. Patients who remain within their vehicle and cannot leave without assistance are considered 'trapped'.

When a patient is trapped in a vehicle, they are considered at higher risk of significant injury than patients who are not trapped. Prolonged entrapment and/or intrusion into the patient compartment is considered high risk for significant injury and therefore features as part of the risk stratification of commonly used major trauma decision-making tools [67,69,161,165,194–196]. Fire and Rescue Service (FRS) delivered extrication strategies have evolved based on the paradigm of movement mitigation to avoid exacerbation of potential spinal injury; such strategies can take a significant amount of time (median 30, IQR 24–38 minutes [141]. FRS teaching mandates that all casualties should be considered to have spinal trauma (and therefore subject to an extrication) until proven otherwise road traffic accident [11].

Patients who are trapped after an MVC may have other time-critical injuries which are not amenable to intervention whilst the patient remains trapped – furthermore, being trapped prolongs scene time with a subsequent delay in accessing definitive care, such as surgical haemostasis [20]. Currently there is a paucity of evidence regarding the rate and type of spinal injuries of those trapped following an MVC, furthermore, we do not have a good understanding of the type and rate of time-critical injuries within this group. Without this understanding extrication approaches cannot be contextualised or understood in terms of potential benefits and harms to our patients.

This study aims to compare the demographics, 30-day mortality, rate and type of spinal injuries and other time-critical injuries between patients trapped and not trapped following an MVC from a UK based national trauma registry. These data will be compared with nationally reported FRS data to understand the number of patients trapped who have major trauma compared to the total number of extrications performed.

Methods

We undertook a retrospective database study using the Trauma Audit and Research Network (TARN) database. TARN is a UK trauma registry to which all Major Trauma

Centres (MTCs) submit data in order to access patient specific tariffs. Since the inception of trauma networks in the UK in 2012, TARN moved from voluntary to mandatory submission of data from participating centres. Eligibility for inclusion on the TARN database includes trauma patients who are admitted to hospital for ≥72 hours, are admitted to a critical care unit, who die in hospital or are transferred to another hospital for specialist care. Patients aged over 65-years with isolated closed fractures of the limbs and hip fractures are excluded from the TARN dataset. TARN includes data on mechanism of injury, which allows patients with certain categories of injuries (e.g. post MVC) to be identified and analysed. MVCs are the second most common cause of trauma recorded on the TARN database (after ground level falls).

TARN uses an outcome prediction model including known confounders of trauma outcomes such as age, sex, injury severity score (ISS), Glasgow Coma Scale (GCS) and Charlson comorbidity index as independent predictors [197]. This allows the calculation of a Probability of Survival for every patient. This is used to build up a Performance Indicator (Ws) which compares groups of patients or institutions. The Ws is used to compare the performance of trauma networks and major trauma centres. The Ws is a directly standardised excess survival rate derived from a difference between the observed and expected number of survivors per 100 patients. A positive value of Ws indicates that the institution has more survivors than predicted, and so its performance is above the standard in the prediction database. The Ws was used in the context of this study to compare outcomes between patients trapped and not trapped, compensating for the confounders listed above.

The TARN database was interrogated to identify major trauma patients who were admitted between January 2012 and December 2018. Patients were excluded whose outcomes were not known, who were admitted outside England, who were not admitted directly and who were not involved in MVCs. Remaining patients were divided into three groups: trapped patients, patients who were not trapped, and those where the status was not recorded. Patients where the entrapment data were not recorded were excluded from further analysis.

Simple descriptive analysis was used to define the characteristics of the trapped and non-trapped groups. The Odds Ratio (OR) was calculated for patient mortality with the Ws used to demonstrate any excess survival difference accounting for included confounders. Levene's test was used to assess equality of variances and a two-tailed t-test to compare means and Mann-Whitney test for comparing medians. Chi square test was used for categorical variables. P values of less than 0.05 were considered significant. SPSS software was used for the analysis.

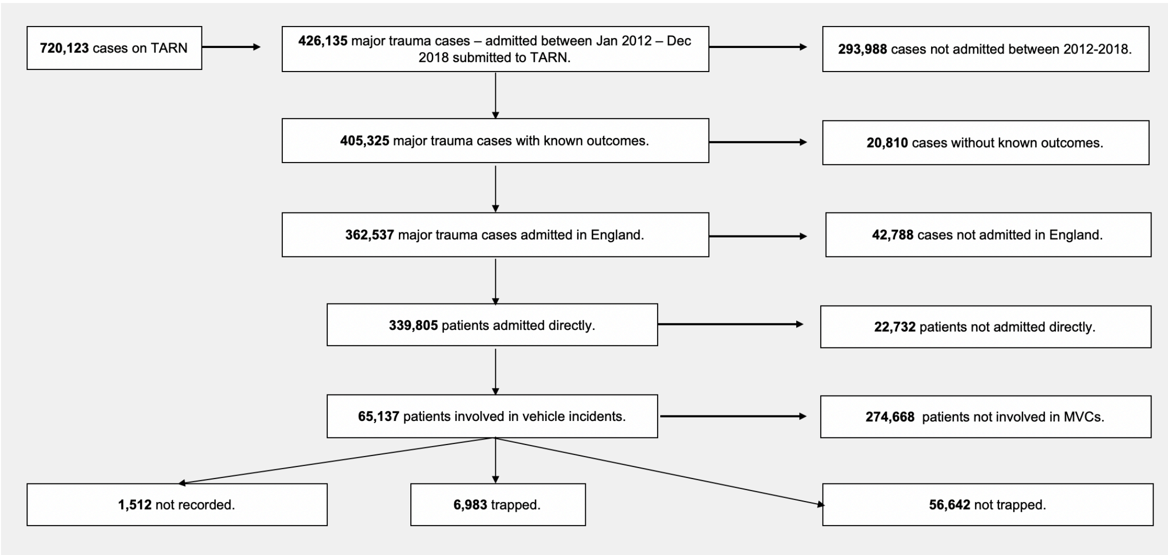
TARN data analyses are conducted using anonymised data which is governed by a code of practice approved by the Confidentiality Advisory Group who are appointed by the Health Research Authority. Additional individual ethical approval was not required for this analysis.

Routinely collected anonymised FRS data, which are reported by central government and available in the public domain, were interrogated to identify the total number of extrications performed in 2012-2018 [198].Simple analysis was used to describe these numbers in context of the spinal and time-critical injury analysis performed.

Results

During the study period, 426,135 major trauma cases were identified on the TARN database. Of these, 65,137 patients were admitted to hospital as a result of an MVC, and in 1,512 the trapped status was not recorded (Figure 1).

FIGURE 3.1: STROBE DIAGRAM



The characteristics of each group are summarized in Table 3.1. The median age (IQR) across all eligible patients was 42.4 (25.1-58.8) years and 73.7% were male. Of patients who survived to hospital, 3568 (5.4%) died within 30 days of initial injury. Across the groups, the mean pre-hospital systolic blood pressure was 131 mmHg, respiratory rate 19 breaths per minute, oxygen saturations 98% with a median GCS of 15.

Table 3.1: Demographics and Mortality by Trapped Status

	Trapped		Not trapped		Sig /p value
Number of patients (%)	6983	(11.0%)	56642	(89.0%)	-
Male n (%)	4374	(62.6%)	42656	(75.3%)	-
Mean Age (ST DEV) years	44.2	(21.3)	43.4	(21.3)	0.003
Median ISS (IQR)	18	(10-29)	13	(9-22)	<0.001
Systolic Blood Pressure mmHg (STD DEV)	129	(31)	133	(27)	<0.001
Respiratory Rate (STD DEV)	21	(7.9)	20	(6.8)	<0.001
Oxygen Saturations (%, STD DEV)	94.8 %	(10.5)	96.3%	(7.5)	<0.001
Median GCS (IQR)	15	(14-15)	15	(13-15)	<0.001
Crude 90 day mortality n, (%)	624	(8.9%)	2804	(5.0%)	<0.001

GCS= Glasgow Coma Score, ISS = Injury Severity Score, IQR = interquartile range, STD DEV = Standard Deviation.

Of the 63,625 patients with a trapped status recorded, 6983 (11.0%) were trapped, with 56,642 (89%) in the not trapped group. Statistically significant differences were found between the two groups across the parameters identified in Table 3.1: age (p= 0.003), systolic blood pressure (p<0.001), respiratory rate (p<0.001), oxygen saturations (p<0.001) and GCS (p<0.001). Being trapped was associated with a worse 30-day mortality outcome (trapped, 8.94%, not trapped 4.95%, OR 1.88 (95% CI 1.72-2.06). Corresponding adjusted excess survival score (Ws) for those that were not trapped was 0.56 (0.31 - 0.8), and for those that were trapped was -0.79 (-1.39 - -0.2). A negative score indicates that unexpected deaths occurred from what was predicted from the model.

Multiple spinal fractures, dens fractures, unstable spinal fractures and cord injuries all occurred more frequently in the trapped group ($p<0.001$); this association did not reach statistical significance with compression fractures ($p = 0.6$).

Table 3.2: Time-critical and Spinal Injuries by Trapped Status

	Trapped (n / %)		% of Extrications*	Not trapped (n / %)		Sig / p value:
Pelvic ring with blood loss > 20% n (%)	69	(1.0%)	0.16	370	(0.7%)	0.001
Blood loss >20% n (%)	244	(3.5%)	0.56	1057	(1.9%)	<0.001
Tension Pneumothorax n (%)	105	(1.5%)	0.24	472	(0.8%)	<0.001
Multiple Spinal Fractures n (%)	942	(13.5%)	2.16	5003	(8.8%)	<0.001
Spine Dens: Fracture n (%)	146	(2.1%)	0.33	586	(1.0%)	<0.001
Spine: Compression Fracture n (%)	118	(1.7%)	0.27	1006	(1.8%)	0.606
Spine: Unstable Fracture n (%)	635	(9.1%)	1.46	3583	(6.3%)	<0.001
Spine: Cord Injury n (%)	464	(6.6%)	0.71	2687	(4.7%)	<0.001

*Percentage of all extrications performed during matched time period from FRS data that had these injuries

Of 464 trapped patients with a spinal cord injury, other significant injuries were present in 232 (50%) patients. The most commonly affected body area was thorax (48.6%) followed by head (24.3%), abdomen (9.7%) and pelvis (6.7 %). Trapped patients with cord injuries rarely had concomitant time-critical injuries such as blood loss >20% (1.7%), tension pneumothorax (1.5%) or pelvic injury with >20% blood loss (0.6%).

The median ISS for all patients was 13 (IQR 9-24), and was significantly higher in the trapped group, 18 (IQR 10-29), when compared to the not trapped group, 13 (IQR 9-22, $p<0.001$). There was a statistically significant higher rate of severe (abbreviated injury scale (AIS) >= 3) injures to the head, chest, abdomen, pelvis, spine and limbs (all p<0.001) in trapped patients compared to not trapped patients. The association was not present for those with a face AIS code of >= 3.

TABLE 3.3: INJURY SITE BY TRAPPED STATUS

Injury site*	Trapped (n/%)		% of all Extrications**	Not trapped (n/%)		Sig / p value:
Head AIS>= 3, n (%)	1742	(25.0%)	3.99	13060	(23.1%)	<0.001
Face AIS>= 3, n (%)	48	(0.7%)	0.11	307	(0.5%)	0.124
Chest AIS>= 3, n (%)	3699	(53.0%)	8.48	19624	(34.7%)	<0.001
Abdo AIS>= 3, n (%)	858	(12.3%)	1.97	4299	(7.6%)	<0.001
Pelvis AIS>= 3, n (%)	738	(10.6%)	1.69	3487	(6.2%)	<0.001
Spine AIS>= 3, n (%)	795	(11.4%)	1.82	4208	(7.4%)	<0.001
Limb AIS>= 3, n (%)	2275	(32.6%)	5.21	16668	(29.4%)	<0.001

AIS = Abbreviated Injury Scale

* Injuries are not mutually exclusive; patients may have more than one qualifying injury.

**Percentage of all extrications performed during matched time period from FRS data that had these injuries

Trapped patients had a statistically significant higher frequency of pelvic ring injuries with blood loss >20% (p <0.001), other blood loss >20% (p<0.001) and tension pneumothorax (p <0.001), though the rates of all three of these injuries were low in terms of total TARN patients and rare (all <0.25%) when considering all the extrications reported in the UK FRS routinely reported data [198].

Trapped patients more frequently underwent intubation, intercostal drain insertion, received tranexamic acid and blood product resuscitation than their non-trapped counterparts (p<0.001).

Table 3.4: Time-critical Interventions by Trapped Status

	Trapped		Not trapped		Sig. /p
Intubation n (%)	1547	(22.2%)	6998	(12.4%)	<0.001
Intercostal drain n (%)	656	(9.4%)	3099	(5.5%)	<0.001
Administration of TXA n (%)	2871	(41.1%)	10395	(18.4%)	<0.001
Blood transfusion n (%)	1104	(15.8%)	3421	(6.0%)	<0.001

TXA = Tranexamic Acid

Discussion

This study has compared the demographics, 30-day mortality, rate and type of spinal injuries and other time-critical injuries between patients trapped and not trapped following an MVC from a UK based national trauma registry.

Is being trapped associated with an increased mortality?

This study demonstrates a significantly higher mortality in the trapped population. This difference in mortality between the groups remains when known confounders considered in the Ws statistic are accounted for. Our results likely underestimate the effect of entrapment on mortality as patients who died on scene were not included in our analyses.

Are spinal injuries common in patients who are trapped?

In high-income countries, patients who are trapped are extricated primarily by the FRS. The principles of extrication have developed without significant medical input [199] and they are based around movement minimization – specifically movement of the spine. Current FRS guidance suggests that even small movements are intolerable and all patients who have undergone trauma should be considered to have a spinal injury until proven otherwise [11]. This guidance accepts that other life-threatening injuries may be present, but the focus in extrication practice remains on the minimization of spinal movement.

Spinal injuries were infrequent in this study population, with trapped patients with a spinal cord injury representing just 0.71% (or one in 141) of all extrications performed. For the very small proportion of patients whom extrication techniques are targeted towards there is a very large number of patients with no or minor injuries (patients not on the TARN registry) whom as a result of application of movement minimization techniques consume significant resources. In addition, there is a large number of severely injured patients who have non-spinal or spinal and additional injuries who extrication approaches are not optimised for.

Do patients with spinal injuries have other injuries which may dictate extrication needs?

In the context of prevention of secondary spinal injury, those patients who may benefit from movement minimization are those who have both a spinal cord injury and do not have other time-critical injuries that may take precedence when planning an extrication. This is a rare patient group; just 232 patients over the six years that this study covers, or 0.5% of the 43,633 total extrications (as recorded on the FRS database) that occurred. As isolated cord injury represents a small proportion of those who are trapped in their vehicles with injuries, extrication principles should therefore be reconsidered with a wider appreciation of the mortality and morbidity associated with other common injuries and injury patterns e.g. blood loss and tension pneumothorax. Within our data, for example, a trapped patient is five times more likely to have a chest AIS of 3+ than a spine AIS of the same severity (Table 3.3).

The findings of increased number and severity of injuries in those who are trapped are consistent with previous evidence. Palanca *et al.* performed univariate and multivariate analysis on 621 patients involved in road traffic collisions presenting to a single centre. Two hundred and fifty-three patients had major injury defined as ISS >15 [161]. They identified the need for extrication as an independent risk factor for severe injury ($p<0.0001$; OR 2.9 (1.9-4.5)). In another large prospective study of 2363 patients, Lerner *et al.* examined numerous pre-hospital factors associated with MVCs [165]. They found that prolonged extrication (>20 minutes) predicted MTC need with a sensitivity of 11% and a specificity of 98%, likelihood ratio 3.6 (2.2 – 5.9).

Injuries in context of intervention when the patient remains trapped?

A large number of patients in our study required life-saving interventions (OR (95% CI), such as intubation (2.02 (1.90-2.15)), decompression of a tension pneumothorax (1.79 (1.64-1.96), or blood product transfusion (2.92 (2.72-3.14), and trapped patients were more likely to require these interventions than their not trapped counterparts (p<0.001). It is challenging to deliver these interventions safely and effectively to a patient that is trapped, due to the working environment, space constraints and inability to do a detailed physical examination. It has been suggested that rapid extrication, minimising the time the patient is trapped, may offer significant benefits. Kaiser *et al.* reinforce this need in their report on 446 traumatically injured patients where they performed a regression analysis to predict the need for urgent surgery [200]. They identified that prolonged extrication (> 30 minutes) was associated with an increased need for emergency surgery (odds ratio 2.3 (1.2-4.6).

Severe chest injuries are common in the trapped patients reported here. Chest injuries are often time sensitive and though they may be temporised by interventions such as supplemental oxygen, decompression of tension pneumothorax and analgesia, they are generally not amenable to definitive pre-hospital treatment. Delivering interventions is further hampered when a patient remains trapped in a vehicle, where oxygen may be contraindicated (due to ignition risk), technical procedures are difficult [124] and pauses for medical assessment and/or intervention further lengthen the time of extrication [141].

Those caring for patients who are trapped in cars should be aware of the frequency, severity and type of injuries which affect this patient group. FRS are often present at the scene prior to the arrival of an ambulance crew. Consideration should be given to how these personnel are trained and how their trauma skillset is relevant and proportional to this patient group.

Limitations

Trapped patients are recorded on the TARN database as “patients that are involved in a vehicle collision and needed to be cut free”. Data entry personnel submitting data to TARN will rely on the “trapped” data box being completed on the ambulance service patient report form. It is not known how reliably this data is recorded on the patient report form and it cannot tell us if a patient was physically trapped or medically trapped. The inability of this dataset to determine between these groups of patients is a potential weakness of this study.

Approximately 88% of trapped patients are ‘medically trapped’, meaning they are unable to leave the vehicle due to pain, their injuries, or they are advised not to move in such circumstances [173]. This type of entrapment is also be termed ‘relative entrapment’.

Alternatively, patients may be ‘physically trapped’, which ordinarily refers to an event where the structure of the vehicle has changed by the application of external force preventing the patient from exiting the vehicle. This could be a simple issue, such as a door lock no longer working, or a more complex issue, for example a patient being pinned in the vehicle due to displacement of the dashboard. Where an impact is such that the internal structure of the car is displaced this is termed ‘intrusion’. An alternative term applied to patients physically trapped is ‘actual entrapment’ [201,202]. Patients can also be physically trapped by external objects such as road furniture and there is an additional cohort of patients who are both physically and medically trapped.

Medically trapped patients would normally be extricated rapidly with minimal cutting of the vehicle whereas physically entrapped patients may require significant resource by the FRS before the patient can be extricated. Previous work in this area has identified that approximately 12% of patients are physically trapped, which is similar to the 11% we report here [173].

A further limitation of this study is that, by using TARN data, it does not include patients who were not eligible for TARN inclusion or patients that died at scene or in transit to hospital. Patients who die at the scene of an incident may have different injuries to those who survive to hospital admission e.g. airway obstruction or impact brain apnoea [203]. Review of coroners records have found the most common cause of death at scene was haemorrhage (35.7%), followed by neurotrauma (32.7%), and then combined haemorrhage and neurotrauma (31.6%) [204]. Inclusion of patients that died at scene would improve the robustness of these findings and give us further insight into and allow us to prioritise which interventions, training and extrication approaches should be prioritised to reduce the mortality associated with entrapment MVC.

Conclusions

Trapped patients are more likely to die than those who are not trapped. The frequency of spinal cord injuries is low accounting for approximately 0.7% of all patients extricated. Patients who are trapped have a high rate of time-critical injuries requiring rapid intervention. Extrication takes time and when considering the frequency, type and severity of injuries reported here, the benefit of movement minimisation may be outweighed by the additional time taken. Improved extrication strategies should be developed which are evidence-based and allow for the expedient management of other life-threatening injuries.

Chapter 4: Sex-disaggregated analysis of the injury patterns, outcome data and trapped status of major trauma patients injured in motor vehicle collisions: a pre-specified analysis of the UK trauma registry (TARN)

Declaration from author and co-authors

The following co-authors contributed to the publication: Weekes L, Heidari S, Fenwick R, Bouamra O, Smith JE, Stassen W.

Contributions of the authors were as follows: TN, LW, SH, RF, JS and WS contributed to the conception and study design, analysis and interpretation of data, drafting and revising the manuscript. OB contributed to the analysis and interpretation of the data and critically revised the manuscript. All authors read and approved the final manuscript.

The extent of contributions from each person are as follows:

- TN: 50%
- SH: 7.5%
- JES: 5%
- LW: 7.5%
- RF: 5%
- OB: 10%
- WS: 15.0%

Given the large number of co-authors, the principal investigator and the supervisor hereby sign for approval on behalf of the group, in accordance with the UCT Doctoral Degrees Board guideline titled, “GUIDELINES FOR THE INCLUSION OF PUBLICATIONS IN A DOCTORAL THESIS.”

	25 July 2022
Tim Nutbeam	Date
	25 July 2022
Willem Stassen	Date

Abstract

Objectives

To identify the differences between women and men in the probability of entrapment, frequency of injury, and outcomes following an MVC. Publishing sex-disaggregated data, understanding differential patterns and exploring the reasons for these will assist with ensuring equity of outcomes especially in respect to triage, rescue and treatment of all patients.

Design

We examined data from the Trauma Audit Research Network (TARN) registry to explore sex differences in entrapment, injuries and outcomes. We explored the relationship between age, sex and trapped status using multivariate logistical regression.

Setting

TARN is a UK based trauma registry covering England and Wales.

Participants

We examined data for 450,357 patients submitted to TARN during the study period (2012-2019) of which 70 027 met the inclusion criteria. There were 18,175 (26%) female and 51,852 (74%) male patients.

Primary and secondary outcome measures

We report difference in entrapment status, injury and outcome between female and male patients. For trapped patients we examined the effect of sex and age on death from any cause.

Results

Female patients were more frequently trapped than male patients (15.8% female(F), 9.4% male (M) $p<0.0001$). Trapped male patients more frequently suffered head (M 1318 27.0%, F 578 20.1%), face, (M 46 0.9%, F 6 0.2%), thoracic (M 2721 55.8%, F 1438 49.9%), and limb injuries (M 1744 35.8%, F 778 27.0%), all $p<0.0001$. Female patients had more injuries to the pelvis (F 420 14.6%, M 475 9.7%, $p<0.0001$) and spine (F 359 12.5%, 485 9.9%, p0.001). Following adjustment for the interaction

between age and sex, ISS, GCS and the Charlson comorbidity index, no difference in mortality was found between female and male patients.

Conclusions

There are significant differences between female and male patients in the frequency at which patients are trapped and the injuries these patients sustain. This sex-disaggregated data may help vehicle manufacturers, road safety organisations and emergency services to tailor responses with the aim of equitable outcomes by targeting equal performance of safety measures and reducing excessive risk to one sex or gender.

Strengths and limitations of this study:

- We include data from 70,027 patients over a 8-year time period.
- The source dataset is of high quality; the Trauma Audit and Research Network (TARN).
- The dataset does not allow clear differentiation between patients that are 'medically trapped (e.g., due to pain) or 'physically trapped' (e.g. due to intrusion into the vehicle)
- We pre-specified outcome measures to minimise bias but the inherent concerns of a retrospective cohort analysis remain.
- We only include patients who meet the threshold for inclusion to TARN and therefore miss MVCs where severe injury did not occur.

Key words

Extrication, Sex, Gender, Motor Vehicle Collision, Accidents, traffic, Spinal injuries, Pre-hospital care, Emergency Medical Services

Background

Sex refers to the biological attributes of humans and animals associated with physical and physiological characteristics such as reproductive anatomy, gene expression, chromosomes and hormone profiles. It is usually categorized as male or female, although there are other variations in sex characteristics [205].

Gender refers to the societal overlay of roles, behaviours and identities ascribed to individuals. It influences how people see themselves, how they are perceived by others; societal bias affects distribution of power and resources. Gender identity refers to individual's deeply felt internal and individual experience of gender. Gender identity is a spectrum and are not restricted to man and woman. An individual's gender identity may differ from their sex assigned at birth [205].

Research outcomes may depend on patient sex (such as medication trials, where sex hormones may affect efficacy), gender (e.g., in trials where actual or perceived behavioural differences may be important) or both. The Trauma Audit and Research Network (TARN) dataset includes sex as recorded on the hospital notes and may represent either sex assigned at birth or gender.

Historical epidemiological data describes major trauma secondary to injury in the UK as predominantly a disease of young men [206]. More recent analysis demonstrates that this paradigm no longer applies, with particular focus on the burden of trauma in the older population [207,208]. Despite increasing awareness of these changing demographics, trauma systems remain tuned to recognising and treating historical perceived norms [194,208].

Motor vehicle collisions (MVCs) are a significant cause of morbidity and mortality throughout the world accounting for 1.35 million deaths and between 20 and 50 million injuries worldwide per annum [194]. To our knowledge no studies have considered the differences in injury patterns, entrapment status and morbidity and mortality outcomes between female and male patients. Failure to collect and analyse sex-disaggregated data is a common concern in research; whilst most studies present baseline demographic data by sex, far fewer report outcome data by sex or conduct sex and gender-based analysis (SGBA) [205,209]. Failure to carry out SGBA can have serious consequences for patient outcome. As an example, female patients are 50% more likely to be misdiagnosed when experiencing a myocardial infarction due to persistent gender-blind research which overlooked different presentation of symptoms in women compared to men. Women's symptoms have been labelled 'atypical' despite being experienced by half of the population [210].

Following an MVC some occupants will be trapped and be unable to exit the vehicle without assistance [211]. Those who are physically trapped will require the assistance of fire and rescue services to perform a mechanical intervention to the vehicle to create space for extrication [173]. Patients who are medically trapped due to pain or disability will require physical assistance, analgesia and the application of spinal precautions or reassurance that such precautions are not required. Patients who are trapped have worse outcomes than those who are not trapped [211].

We could find no previous sex-disaggregated data which report injury patterns for patients trapped following an MVC. This information would be useful for those triaging, rescuing or treating patients. There may be additional value of sex-disaggregated data to target public health interventions and the design of safety systems such as restraint devices and airbags.

The aims of this study were to define the probability of entrapment, frequency of injury, and outcomes by the sex of the casualty.

Methods

A retrospective review of the UK Trauma Audit and Research Network (TARN) database was carried out including patients injured between 1st January 2012 and 31st December 2019. TARN collects data from Major Trauma Centres and Trauma Units in the UK. Eligibility criteria for inclusion in the TARN database include trauma patients who are admitted to hospital for ≥72 hours, or are admitted to a critical care unit, or die in hospital or are transferred to another hospital for specialist care. Pre-hospital deaths, isolated closed fractures of the limbs and hip fractures in patients over the age of 65 are not included. TARN includes routine data on patient demographics, physiology, interventions, injuries and in some circumstances (including MVCs) the trapped status of the patient.

Inclusion criteria were patients aged 16 years or older, with mechanism coded as "Vehicle Incident/Collision", directly admitted to a TARN participating hospital in England and with complete documented outcomes. To ensure data quality, patients were excluded if they underwent secondary transfer from another hospital or when the trapped status was not documented on the database.

For patients that met the inclusion criteria, data fields including sex, age, trapped status, injury severity score (ISS), abbreviated injury scale (AIS) for each body region, any details of spinal injury and significant time dependent injuries as described in previous work were made available for analysis [211].

Simple descriptive analysis was used to define the characteristics of the female and male groups. Levene's test was used to assess equality of variances and a two-tailed t-test to compare means and Mann-Whitney test for comparing medians. Chi square test was used for categorical variables. *P* values of less than 0.01 were considered significant due to multiple analyses being performed. The relationship between age, sex, and trapped status was explored further using multivariate logistical regression. SPSS (IBM Corp v.23 Armonk, NY) and Stata (StataCorp. 2015. Stata Statistical Software: Release 14. College Station, TX) were used for the analyses. Additional analyses which were not pre-specified; injuries of patients who were excluded for incomplete entrapment data, injuries sustained by year over time, and a passenger / driver analysis. Analyses which are not prespecified are included in the supplemental file.

TARN data analyses are conducted using anonymised data which is governed by a code of practice approved by the Confidentiality Advisory Group who are appointed by the Health Research Authority. Additional individual ethical approval was not required for this analysis.

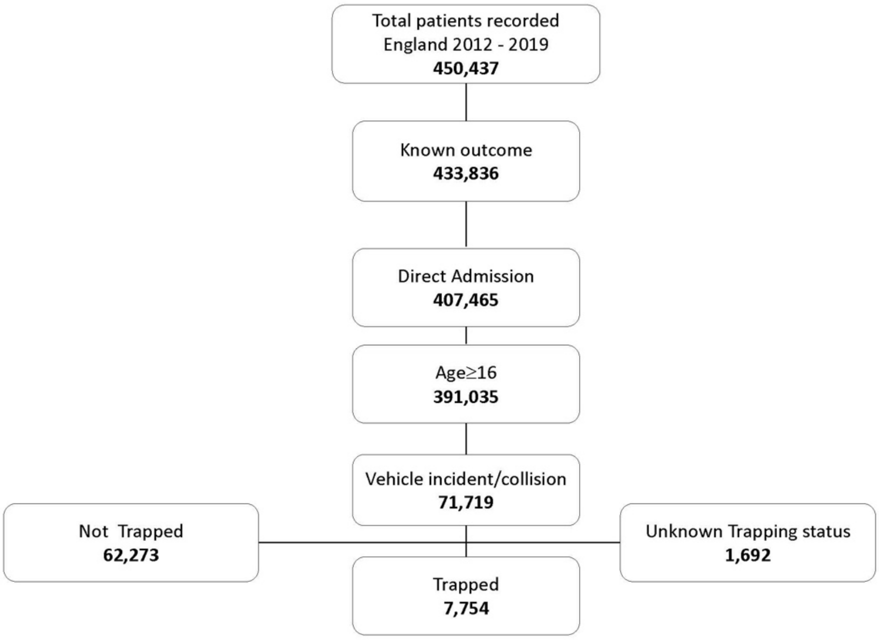
Patient and public involvement

TARN has patient and public involvement on the TARN Board which has oversight of the research portfolio. For this specific analysis we sought the opinions of the advocacy group GENDRO.

Results

Between 2012 and 2019, there were 450 437 cases identified in total on the TARN database. Following exclusions, data for 71,719 patients from an MVC were identified of which 70,027 patients had a known trapped status were analysed (Figure 1).

FIGURE 4.1: STROBE DIAGRAM



The characteristics of each group are summarized in Table 4.1. Twenty-six percent of patients were female. The average age (SD) across all eligible patients was 46.2 (20.1); female patients were older than male patients (52.4 (SD 22.0) vs 44.1 (SD 18.9), p=<0.0001). Female patients had less severe injury (p<0.0001). Mean (median for GCS) physiological variables were similar for female and male patients. Small differences in heart rate, respiratory rate and oxygen saturations demonstrated statistical but not clinically significant differences.

Of patients who survived to hospital, 3,868 (5.5%) died within 30 days of initial injury. Female patients had statistically worse survival although the difference was small (94.0% versus 94.6%, p=0.001). A higher proportion of female patients were trapped than male patients (p=<0.0001). Of the population of patients who were trapped, female patients had better outcomes (92.3% alive at 30 days compared to 90.0% of males, p=0.01).

TABLE 4.1: DEMOGRAPHICS, OUTCOMES AND PHYSIOLOGY

	All Trapped and Not Trapped							Only Trapped				
	Total		Female		Male		p value	Female		Male		p value
Number (%)	70027		18175	(26.0)	51852	(74.0)	<0.0001	2879	(37.1)	4875	(62.9)	<0.0001
Age (mean, SD)	46.2	(20.1)	52.4	(22.0)	44.1	(18.9)	<0.0001	50.1	(21.8)	42.9	(19.7)	<0.0001
ISS (Median, IQR)	13	(9-22)	13	(9-22)	13	(9-24)	<0.0001	17	(9-27)	19	(10-29)	<0.0001
Driver of vehicle (%)	16600		5132	(30.9)	11468	(69.1)	<0.0001	1623	(31.9)	3471	(68.1)	<0.0001
Systolic Blood Pressure (mean, SD)	133.3	(28.0)	133.1	(30.2)	133.4	(27.2)	0.361	128.7	(30.7)	129.5	(30.9)	0.309
Heart Rate (mean, SD)	86.7	(22.2)	87.9	(21.9)	86.2	(22.3)	<0.001	91.2	(24.2)	92.1	(26.3)	0.185
Respiratory Rate (mean, SD)	20.3	(6.9)	20.3	(6.7)	20.3	(7.0)	0.833	21.3	(7.3)	21.5	(8.2)	0.207
Oxygen Saturation (mean, SD)	96.1	(7.9)	96.2	(7.3)	96.0	(8.0)	0.001	97.4	(5.9)	97.3	(5.9)	0.544
GCS ISS (Median, IQR)	15	(15-15)	15	(15-15)	15	(15-15)	n/a	15	(1415)	15	(14-15)	n/a
Alive at 30 days (n,%)	66159	(94.5)	17084	(94.0)	49075	(94.6)	0.001	2657	(92.3)	4396	(90.0)	0.01

Table 4.2 and 4.43 show that trapped female and male patients demonstrated significant differences in the incidence of thoracic and spinal injuries. Tension pneumothorax was more common in male patients and dens fractures were more common in female patients (both $p<0.0001$). Spinal cord injuries were also more common in female patients ($p=0.038$). When trapped, male patients were more likely to suffer from head, face, thoracic and limb injuries (all $p<0.0001$, Table 4.3), while female patients were more likely to have pelvic ($p<0.0001$) and spinal injuries ($p<0.001$). The incidence of abdominal injuries was similar in female and male patients.

Table 4.2: Significant injuries by sex for trapped casualties

	Female	**%**	**Male**	**%**	**P value**
Pelvic ring fracture with blood loss >20%	23	0.8	48	1.0	0.394
Blood loss>20% (%)	114	4.0	161	3.3	0.139
Tension pneumothorax (%)	26	0.9	92	1.9	<0.0001
Multiple spinal fractures (%)	429	14.9	649	13.3	0.54
Dens fracture (%)	85	3.0	79	1.6	<0.0001
Spinal compression fracture grade 2/3 (%)	66	2.3	75	1.5	0.022
Unstable spinal fracture (%)	276	9.6	441	9.0	0.43
Spinal cord injury (%)	218	7.6	308	6.3	0.038

TABLE 4.3: INJURY SITE BY SEX FOR TRAPPED CASUALTIES

	Female	%	Male	%	P value
Head AIS 3+	578	20.1	1318	27.0	<0.0001
Face AIS 3+	6	0.2	46	0.9	<0.0001
Thoracic AIS 3+	1438	49.9	2721	55.8	<0.0001
Abdomen AIS 3+	355	12.3	595	12.2	0.87
Spine AIS3+	359	12.5	485	9.9	0.001
Pelvic AIS 3+	420	14.6	475	9.7	<0.0001
Limb AIS 3+	778	27.0	1744	35.8	<0.0001

AIS = Abbreviated Injury Scale , Injuries are not mutually exclusive; patients may have more than one qualifying injury

Figure 4.2 demonstrates the interaction between adjusted mortality, trapped status and age. This analysis adjusts for the interaction between age and sex, ISS, GCS and the Charlson comorbidity index. In this adjusted analysis, trapped male patients were more likely to die but the 95% confidence intervals overlapped between the male and female groups for all age categories.

FIGURE 4.2: ADJUSTED MORTALITY AND AGE (Error bars = 95% Confidence Intervals)

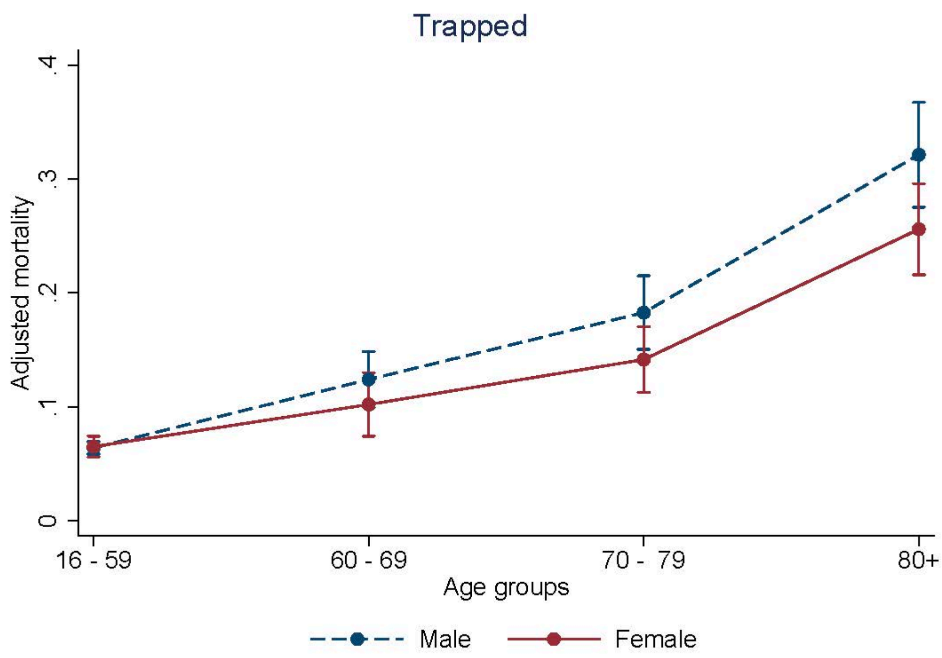
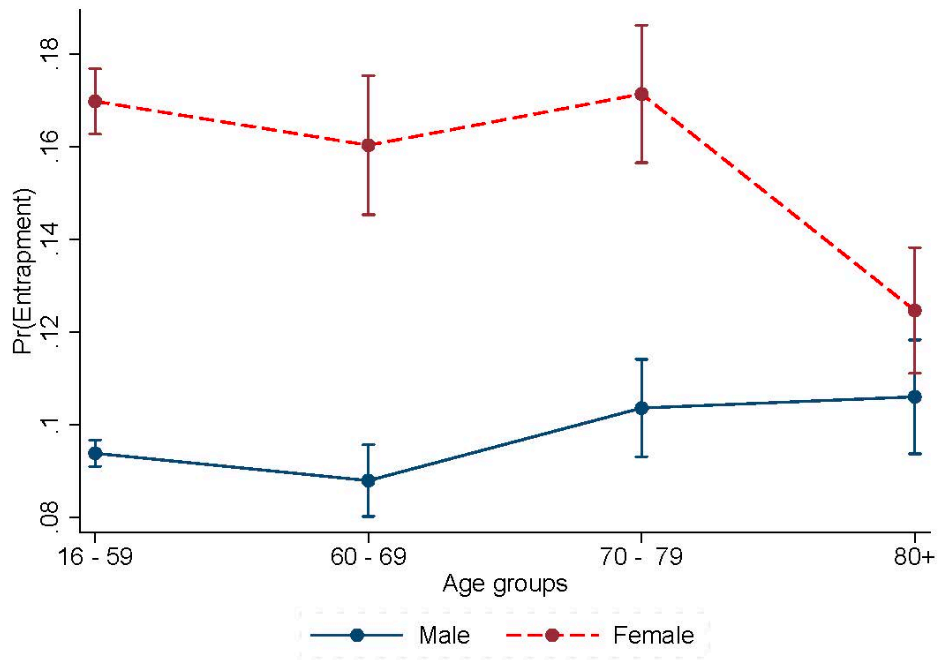


Figure 4.3 displays the interaction between probability of entrapment, sex and age. Female patients were more likely to be trapped in all the age groups considered except in patients aged 80 and over.

FIGURE 4.3: PROBABILITY OF ENTRAPMENT AND AGE (Error bars = 95% Confidence Intervals)



Discussion

This is the largest analysis to date of sex-disaggregated data for trauma patients following an MVC and confirms significant differences in injury patterns and trapped status between female and male patients.

The explanations for these differences are likely to include both reasons pertaining to biological sex e.g. physical size, muscle mass, hormonal differences and reasons pertaining to gender such as driving behaviours, post-collision behaviours, and responses by emergency responders such as decisions related to extrication.

Female patients in this analysis had a lower ISS and tended to be older than male patients. These differences were more apparent in those patients that were trapped. The recorded physiological observations are broadly similar between sexes.

There are gender-related differences that may contribute to the observed differences. Men drive more miles, faster, in a riskier manner and more frequently have accidents, resulting in the higher injury burden and mortality as seen in this analysis and elsewhere [212–215]. Women make up a higher proportion of older drivers [216]. Older women are more likely than men of equivalent age to be killed or seriously injured in collisions, after controlling for miles driven; whereas young men have the highest risk of serious injury or death per million miles driven [213].

Trapped male patients were more likely to have severe injuries of the head, face, chest (including tension pneumothorax) and limbs, with female patients more likely to have injuries of the vertebrae, spinal cord and pelvis. No statistically significant differences were found between trapped female and male patients in relation to pelvic ring injuries with blood loss, multiple spinal fractures or abdominal injuries.

Differences in injuries may be accounted for by i) differences in car usage, kinematics, and mechanism of injury (MOI), ii) differences in effectiveness and availability of safety systems and iii) differences in biological propensity to certain injury types.

Difference in kinematics and resultant mechanism of injury

An analysis of the UK-based STATS-19 MVC registry demonstrates that male drivers are more likely to have MVCs whilst travelling forwards (64.2% vs 56.5%) whereas female drivers are more likely to have collisions whilst manoeuvring (16.1% vs 11.9%) or turning (10.7% vs 8.4%). Similar findings are reported in the United States, with female patients more likely to be involved in a side impact MVC and male patients more likely to have a frontal impact [217]. Side impact MVCs result in a transfer of energy to the patient that is more likely to cause significant spinal injury [218]. Side impacts are also a common cause of lateral compression fractures of the pelvis [219,220] which may explain the finding of an increased prevalence of these injuries in female patients. It is rare for lateral compression fractures of the pelvis to be associated with significant bleeding which perhaps accounts for the higher rate of pelvic fractures in female patients but not a high rate of pelvic fractures with significant blood loss [221].

Male patients experience a higher rate of frontal collisions, which may account for the increased rate of head, face and chest injury found in this study, through interactions and resultant energy transfer with the steering wheel and/or air bag [222,223]. The higher rate of male drivers and their interactions with the pedals and the "bracing" experienced by drivers pre-collision may explain the higher rate of limb injury seen in male patients in this study [224,225].

Differences in availability and effectiveness of safety systems

Safety systems are less effective for passengers than drivers and are optimised to minimise energy transfer from frontal collisions [224,226,227].

It has been previously demonstrated that women are more likely to be compliant with safety systems such as seat belts than men and as a result have less risk of multiple and severe injuries and their associated mortality [228,229]. However, the safety features incorporated in modern cars are less likely to be effective for women. Current mandatory crash testing uses a scaled-down 50th centile male mannequin to represent 5th percentile females and are not modelled to account for anthropometric differences between females and males [230–233]. This systemic bias, with cars developed, tested and safety-rated using primarily an anatomically correct, weighted and biomechanically-matched male mannequin has led to the development of safety systems which are likely to be more effective for males than females. For example, whiplash protection systems are significantly more effective at preventing injury in men than women [231,234]. Comparison of female and male dummies demonstrates higher biomechanical response in the female dummy in the neck region which may offer some explanation for the increased rate of spinal fractures in female patients found in our study [235].

Moreover, female patients are more likely to drive and be injured in smaller cars, with less efficient safety systems. Smaller cars are associated with a greater injury burden and may account for some of the sex-related differences seen in this study [236].

Female patients are biologically prone to certain injury types

The intersection of age, biological differences, female propensity to injury and medical conditions such as osteoporosis may further account for some of the differences in injuries seen in this analysis [237]. Females and males differ physically in ways which are pertinent to injury and entrapment in RTCs. They each have unique anthropometry for example: females have wider pelvic measurements and shorter torsos, even controlled for height difference [238]. As such, female pelvic geometry may be more prone to injury following a side impact [239]. A combination of these factors may explain the differences seen in injury patterns in this study; we found a greater proportion of pelvic fractures in females, and a higher rate of head and chest injury in male patients.

Sex hormones affect body composition. Testosterone contributes significantly greater skeletal muscle mass (8% greater, after correcting for BMI) in males, which does not start to fall until the fifth decade [240]. Female sex hormones are responsible for ligaments in females being more lax, which combined with females' cervical vertebrae being smaller than males of equivalent head size, may explain the greater rate of spinal cord injury in females[241,242]. Post-menopausal changes in bone composition mean that females have a 50% greater loss of bone in old age compared to males, again making them susceptible to fractures as a result of MVC [237].

Female patients were more likely than male patients to be trapped (15.8 vs 9.4%, $p<0.0001$). The mean age of trapped female patients was significantly higher than trapped male patients; this may influence their own ability to self-extricate due to frailty or relative immobility [243]. An additional possible explanation may include different treatment by rescuers, for example, perhaps being less likely to recommend or facilitate self-extrication for older females. Females are more likely to sit closer to the steering wheel, meaning that less movement intrusion of the dashboard and steering wheel is required to cause entrapment [244]. Furthermore, this study found that female patients are more likely to have injuries of the pelvis and spine and these injuries may prevent self-extrication and increase the frequency of entrapment.

Post-collision behaviour and patient experience differences between female and male patients may contribute to the increased rate of entrapment in females, who are more likely to experience multi-region and widespread pain following an MVC, which may prevent them leaving the vehicle without assistance [245]. TARN does not record whether a patient was physically trapped by vehicle deformation or medically trapped (e.g. by pain) which prevents further analysis within this dataset.

Trapped female patients had a lower ISS than trapped male patients and were less likely to die (7.7% vs 10.0%). However, once the factors in our model were considered (age, sex, ISS, GCS and Charlson co-morbidity index) no difference in mortality was found between female and male patients (Figure 2).

This study shows that men and women experience different rates of entrapment and different injury patterns when involved in MVCs. This may have implications for the design of car safety systems, so as to protect men and women equally. Likewise, for prehospital clinicians, this work highlights the differences seen in clinical practice when attending MVCs.

The higher rate of female entrapment seen may in part be explained by this cohort being older and having greater co-morbidity. Current UK extrication dogma still prioritises 'spinal precaution' methods of extrication that involve the patient being passive in the process. A greater focus on self-extrication as a safe alternative to rescue service assisted extrication may in future reduce the number of medically trapped patients.

Not all patients trapped in an MVC were included in this study due to the TARN inclusion criteria. Of note, pre-hospital deaths from the most severe MVCs are not included, nor were patients who received minor injuries but were physically trapped by mechanical deformation of the vehicle. This study was unable to distinguish entrapment due to medical causes (e.g. pain or relative immobility) from physical entrapment due to vehicle deformity, which implies a greater energy transfer collision. This analysis did not discriminate between the type of vehicle (e.g. car or bus/coach or light/heavy goods vehicle) and includes all occupants of vehicles involved in an MVC which is a heterogenous group. The "trapped" status recorded on TARN has high data completeness with only 2.4% of patients having this element missing; the route of completion varies between centres but is normally taken from the ambulance service patient report form. The "trapped" definition is open to interpretation and cannot distinguish between type and mode of entrapment. These limitations may hinder our interpretation of trapped status.

Conclusions

Male patients are more severely injured and die as a result of MVC than female patients. Female patients under 80 are more frequently trapped than male patients. Female patients are more likely to have spinal and pelvic injuries and male patients are more likely to have head, face, thoracic and limb injuries. Differences in driving behaviours, kinematics, collision type, position in vehicle, the efficacy of safety systems, biological vulnerability to certain injury types and post-injury behaviour may all have influence on these patterns.

Sex-disaggregated data on mortality, entrapment and injury patterns in motor-vehicle collisions may help to inform vehicle manufacturers, emergency services personnel and road-safety organisations to tailor responses with the aim of equitable outcomes by targeting equal performance of safety measures and reducing excessive risk to one sex or gender. Future work should include appropriate sex- and gender-based analyses designed to shed light on the biological and sociocultural factors that create differential experience and outcomes for women and men involved in MVCs.

Chapter 5: Do entrapment, injuries, outcomes and potential for self-extrication vary with age? A pre-specified analysis of the UK trauma registry (TARN)

Declaration from author and co-authors

The following co-authors contributed to the publication: Kehoe A, Fenwick R, Smith JE, Bouamra O, Wallis L, Stassen W.

Contributions of the authors were as follows: TN, AK, RF, JS, LW and WS contributed to the conception and study design, analysis and interpretation of data, drafting and revising the manuscript. OB contributed to the analysis and interpretation of the data and critically revised the manuscript. All authors read and approved the final manuscript.

The extent of contributions from each person are as follows:

- TN: 50%
- AK: 15%
- RF: 5%
- JES: 5%
- OB: 10%
- LW: 2.5%
- WS: 12.5%

Given the large number of co-authors, the principal investigator and the supervisor hereby sign for approval on behalf of the group, in accordance with the UCT Doctoral Degrees Board guideline titled, “GUIDELINES FOR THE INCLUSION OF PUBLICATIONS IN A DOCTORAL THESIS.”

25 July 2022

Tim Nutbeam Date

25 July 2022

Willem Stassen Date

Abstract

Background

Motor vehicle collisions (MVCs), particularly those associated with entrapment, are a common cause of major trauma. Current extrication methods are focused on spinal movement minimisation and mitigation, but for many patients' self-extrication may be an appropriate alternative. Older drivers and passengers are increasingly injured in MVCs and may be at an increased risk of entrapment and its deleterious effects. The aim of this study is to describe the injuries, trapped status, outcomes, and potential for self-extrication for patients following an MVC across a range of age groups.

Methods

This is a retrospective study using the Trauma Audit and Research Network (TARN) database. Patients were included if they were admitted to an English hospital following an MVC from 2012 to 2019. Patients were excluded when their outcomes were not known or if they were secondary transfers. Simple descriptive analysis was used across the age groups: 16-59, 60-69, 70-79 and 80+ years. Logistic regression was performed to develop a model with known confounders, considering the odds of death by age group, and examining any interaction between age and trapped status with mortality.

Results

70,027 patients met the inclusion criteria. Older patients were more likely to be trapped and to die following an MVC ($p<0.0001$). Head, abdominal and limb injuries were more common in the young with thoracic and spinal injuries being more common in older patients (all $p<0.0001$). No statistical difference was found between the age groups in relation to ability to self-extricate. After adjustment for confounders, the 80+ age group were more likely to die if they were trapped; adjusted OR trapped 30.2 (19.8 - 46), not trapped 24.2 (20.1 - 29.2).

Conclusions

Patients over the age of 80 are more likely to die when trapped following an MVC. Self-extrication should be considered the primary route of egress for patients of all ages unless it is clearly impracticable or unachievable. For those patients who cannot

self-extricate, a minimally invasive extrication approach should be employed to minimise entrapment time.

Key words

Older patients, Extrication, Accidents (traffic), Spinal injury, Emergency Medical Services

Background

Motor vehicle collisions (MVCs) are a frequent cause of trauma and death for patients of all ages [211]. Following an MVC some patients will be trapped [211]. Only around 10% of such patients are physically trapped by deformation of the vehicle, requiring dismantling of the vehicle and space creation by rescue services[173]. The overwhelming majority are trapped due to painful injuries inhibiting movement or physiological impairment rendering voluntary movement difficult [4]. However, often it is rescuer or casualty concerns about exacerbating secondary spinal injury which prevent self or minimally assisted extrication [11,246].

Being trapped through any of these mechanisms is associated with excess mortality[211]. It is not yet clear whether this can be mitigated by reducing extrication time [141]. Extrication strategies have historically focused on movement mitigation such as roof removal techniques, which inherently take longer to deliver than self-extrication. However, recent work has demonstrated the biomechanical and time advantages of self-extrication over tool-based techniques [247]. Minimising entrapment time reduces avoidable delays to diagnosis and clinical interventions, whilst also reducing the detrimental effects of environmental exposure. A combination of these factors and others may lead to the excess mortality seen in trapped casualties.

Average life expectancy is increasing throughout most of the world, with the most rapidly growing segment of the population being people aged over 60 years[208]. With this changing demographic, healthcare systems have witnessed a disproportionate rise in older patients suffering from major trauma, with this group now representing over 50% of the major trauma cases reported in the UK [207,208]. There are more older drivers (and passengers) on the roads than ever before, with older road users representing 12% of car driving license holders and 9% of road miles travelled [248,249]. Older patients have a higher mortality rate, with those over 70 representing a disproportionate 20% of all car driver deaths [250].

Older casualties may be at increased risk of entrapment through decreased baseline mobility, a propensity to frailty and vulnerability to certain types of injury[208]. It is unknown if older patients are more at risk from the dangerous effects of prolonged entrapment. Extrication may be delayed due to rescuer perceptions about the incidence of spinal injury in this group and their ability to self-extricate [251].

The aims of this study were to describe the rate of entrapment, the type and frequency of injuries, and outcomes in different age groups, and whether there is disproportionate mortality from entrapment in older patients. We also compared the incidence of factors likely to impede self-extrication between the groups.

Methods

This is a retrospective review of the UK Trauma Audit and Research Network (TARN) database. TARN is the UK national trauma registry into which all Major Trauma Centres submit data on severely injured patients. TARN moved from voluntary to mandatory submission of data from MVCs in 2012. Eligibility criteria include trauma patients who are admitted to hospital for ≥72 hours, are admitted to a critical care unit, die in hospital, or are transferred to another hospital for specialist trauma care. Isolated closed fractures of the limbs and hip fractures in patients over 65 are excluded. TARN includes patient demographics, initial physiology, treatment interventions, detail of injuries and in some circumstances (including MVCs) their trapped status.

This study describes the rate of entrapment by age group, considering the effect of being trapped on outcomes and whether this effect modifies with age. Reporting the rate and type of spinal injuries, other severe potentially time critical injuries and traumatic and physiological challenges to self-extrication by age group will inform choice of extrication strategy [3,252].

Patients were included if they were admitted between January 2012 and December 2019, were involved in an MVC, were admitted directly to an English hospital, and had a known outcome. Patients were excluded when their trapped status was not known. For patients who met the inclusion criteria, data fields including age, trapped status, injury severity score (ISS), abbreviated injury score (AIS) for each body region were reported. In addition we report details of spinal injury and other severe injuries that we have previously defined.

Adults were categorised into age groups: 16-59, 60-69, 70-79 and 80+ years. These age groups were selected as they have previously been defined by TARN [208]. The 80+ age group were considered as a whole to prevent the statistical artifact associated with small sample sizes. Simple descriptive analysis was used to define the characteristics of the groups by age category and trapped status. A two-tailed t-test was used to compare means and Mann-Whitney U test for comparing medians.

The Chi square test for uniform distribution was used for categorical variables. *P* values of less than 0.01 were considered significant due to multiple analyses being performed. Logistic regression was used to develop a model with the following known confounders: sex, ISS, GCS, Charlson comorbidity index and entrapment status as exposure variables, considering the odds of death by age group, and examining any interaction between age and trapped status with mortality. Missing values for GCS were imputed under the assumption of a mechanism of missing at random (MAR). SPSS (IBM Corp v.23 Armonk, NY), Stata (StataCorp. 2015. Stata Statistical Software: Release 14. College Station, TX) and R (Integrated Development for R. RStudio, PBC, Boston, MA, v.1.4) software were used for the analyses.

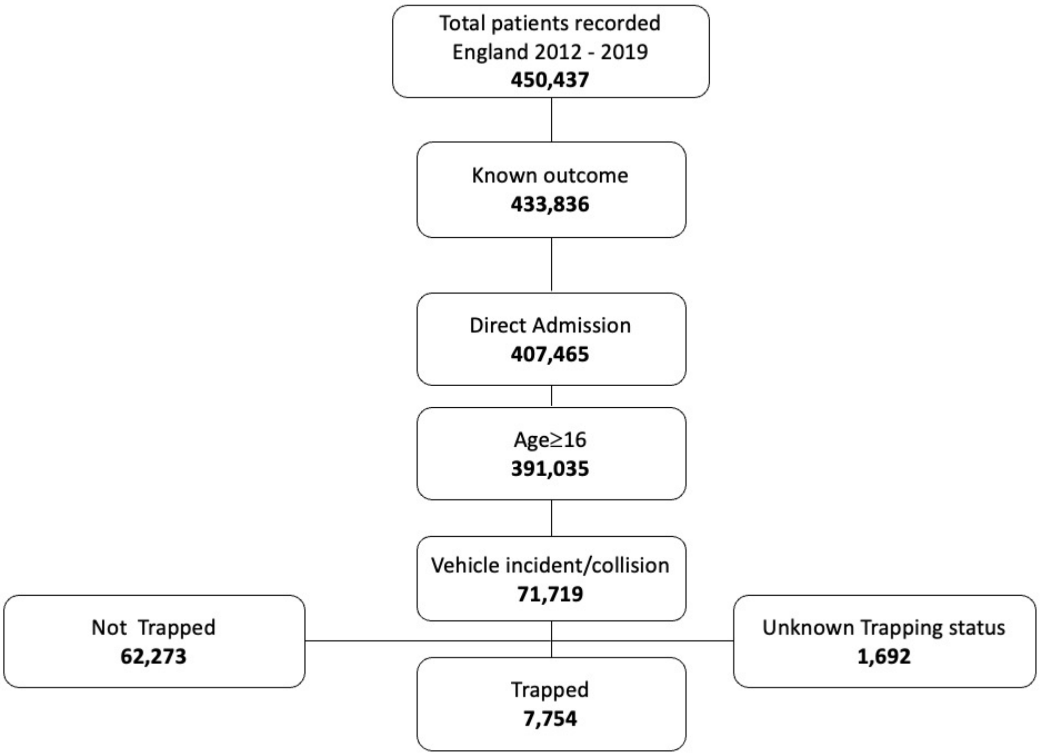
A literature review failed to identify previous studies or guidance which indicates which patients are suitable for self-extrication. All parameters available through the TARN data set were considered by the research group; factors were identified which the group from their clinical and operational experience felt were likely to affect the ability of a patient to successfully self-extricate. Factors where consensus was achieved were GCS 12 or less; Spine, Limb or Pelvis Abbreviated Injury Scale (AIS) score of 3+; or a systolic blood pressure of <90 mmHg. Patients where none of these factors were present were considered as having a high potential for self-extrication.

TARN data analyses are conducted using anonymised data which is governed by a code of practice approved by the Confidentiality Advisory Group who are appointed by the Health Research Authority. Additional individual ethical approval was not required for this analysis.

Results

Between 2012 and 2019 there were 450,437 major trauma cases identified on the TARN database of whom 70,027 met the inclusion criteria (Figure 1).

FIGURE 5.1: STROBE DIAGRAM



The characteristics of each group are summarized in Table 5.1. The systolic blood pressure increased with age, whilst the pulse, respiratory rate, oxygen saturations and GCS demonstrate statistical though not clinical differences between the groups with no age-dependent trend. With large datasets there is a well reported tendency for the identification of statistically significant but clinically inconsequential effects [192].

The median ISS was similar across the age groups. Thirty-day mortality increased with increasing age from 4.1 % (16-59) to 16.4% (80+).

Table 5.1: Demographics and Mortality by Age

Age groups	Total	16 - 59	60 - 69	70 - 79	80+
Total number of cases	70027	51868	7605	5733	4821
Male, n (%)	51852 (74%)	40957 (79%)	5232 (68.8%)	3197 (55.8%)	2466 (51.2%)
ISS, median (IQR)	13 (9 - 22)	13 (9 - 24)	13 (9 - 22)	13 (9 - 24)	13 (9 - 22)
Systolic BP, mean (SD)	133 (28)	129 (25)	140 (30)	145 (33)	149 (34)
Pulse rate, mean (SD)	87 (22)	88 (22)	83 (21)	83 (22)	83 (21)
Respiratory rate, mean (SD)	20 (7)	20 (7)	20 (7)	20 (7)	20 (7)
Oxygen saturation, mean (SD)	96 (8)	96 (8)	96 (8)	95 (9)	95 (7)
GCS, median (IQR)	15 (15 - 15)	15 (15 - 15)	15 (15 - 15)	15 (15 - 15)	15 (15 - 15)
Trapped, n (%)	7754 (11.1%)	5642(10.9%)	807 (10.6%)	756 (13.2%)	549 (11.4%)
Mortality, n (%)	3868 (5.5%)	2125 (4.1%)	391 (5.1%)	564 (9.8%)	788 (16.4%)

GCS Glasgow Coma Scale, IQR interquartile range, SD standard deviation.

Statistically significant differences (p<0.0001) were found across all groups apart from in Respiratory rate and GCS categories.

As shown in Table 5.2, unadjusted and adjusted odds of death increased with age. Trapped patients over 80 had an increased mortality rate compared to those that were not trapped (Figure 5.2). This model performed well, with a discrimination area under the receiver operator curve (ROC, C-statistic) of 0.952 (95% CI 0.948 - 0.955) as shown in Figure 5.3.

TABLE 5.2: TRAPPED STATUS AND MORTALITY BY AGE

	Trapped at scene				Not trapped at scene			
Age groups	**16 - 59**	**60 - 69**	**70 - 79**	**80 +**	**16 - 59**	**60 - 69**	**70 - 79**	**80 +**
Unadjusted Odds Ratio of death (95% CI)	1	1.1 (0.9 - 1.5)	1.7 (1.4 - 2.2)	4.4 (3.6 - 5.5)	1	1.3 (1.2 - 1.5)	2.7 (2.5 - 3.0)	4.6 (4.2 - 5.1)
Adjusted Odds Ratio of death (95% CI)	1	3.7 (2.3 - 5.9)	8.5 (5.5 - 13.3)	30.2 (19.8 - 46)	1	2.8 (2.3 - 3.4)	8.7 (7.2 - 10.6)	24.2 (20.1 - 29.2)

Adjusted for gender, ISS, GCS, Comorbidity

FIGURE 5.2: AGE AND ADJUSTED ODDS OF DEATH

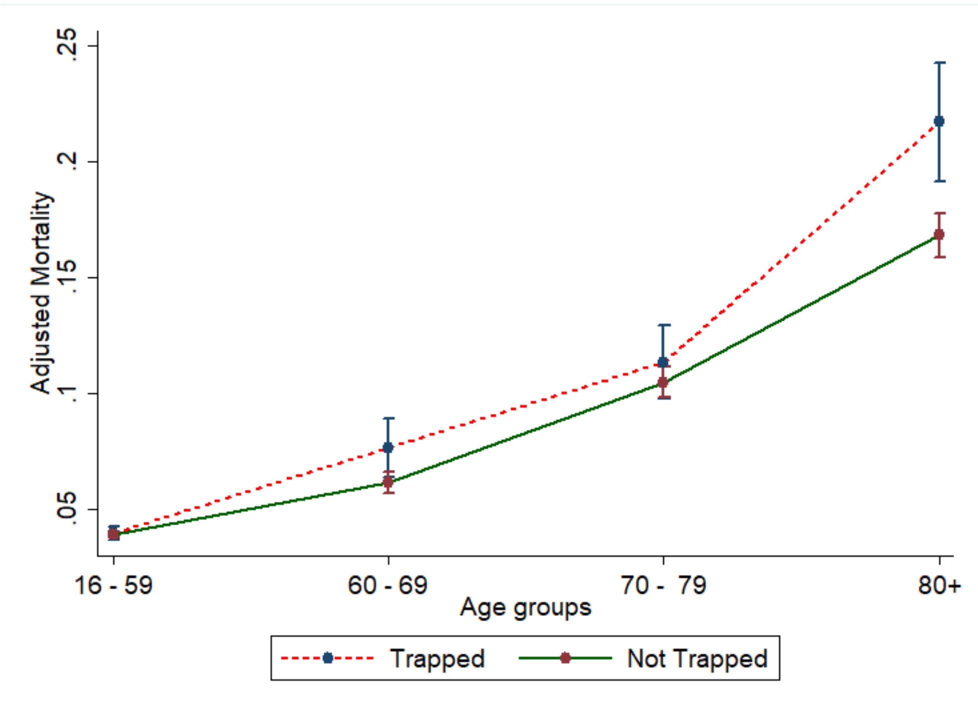
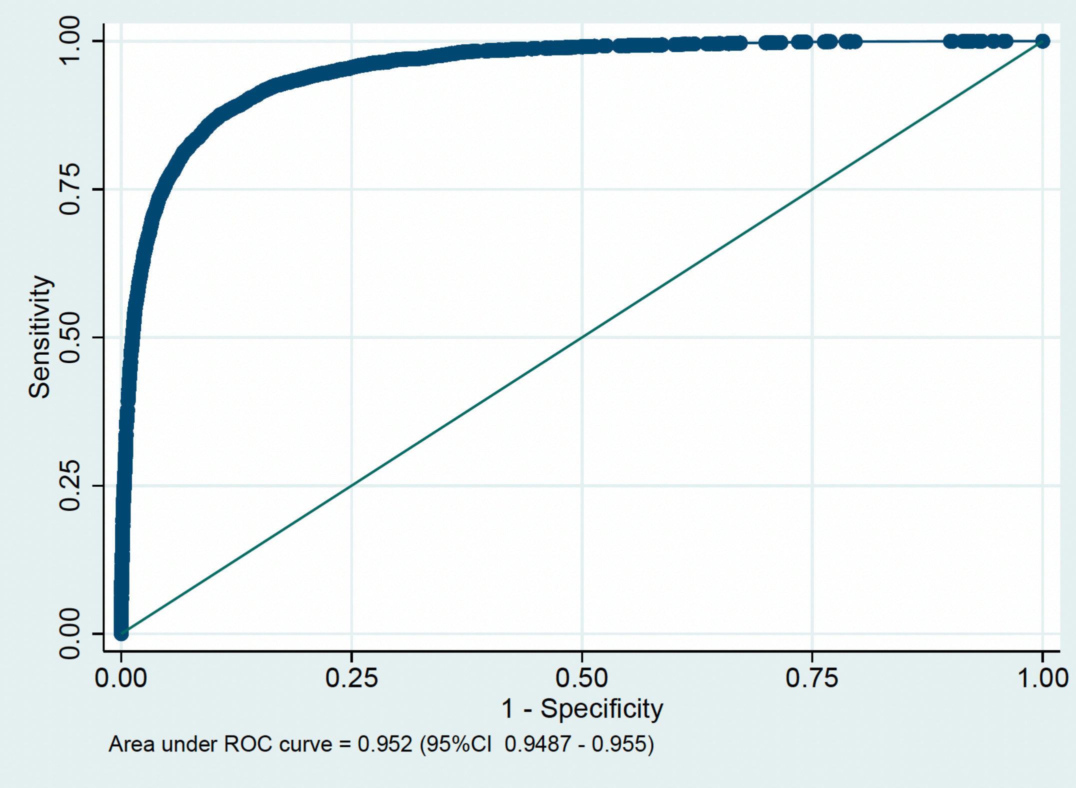


FIGURE 5.3: RECEIVER OPERATOR CURVE FOR MODEL*



*Sex, ISS, GCS, Charlson comorbidity index and entrapment status as exposure variables

In patients who were trapped, severe injuries occurred with similar frequency across all age categories (Table 5.3). Injuries (AIS 3+) to the head, face, abdomen and limbs were more common in the young (16-59, Table 5.4). Thoracic injuries were more frequent in those aged 60 or above.

The frequency of multiple spinal fractures, dens fractures, unstable fractures and cord injuries were highest in the 70-79 age group.

TABLE 5.3: SEVERE AND SPINAL INJURIES BY AGE FOR TRAPPED CASUALTIES

		Age group				
Injury	**Total**	**16 - 59**	**60 - 69**	**70 - 79**	**80+**	**Significance (p)**
Pelvic Ring Blood loss>20%	71 (0.9%)	53 (0.9%)	9 (1.1%)	5 (0.7%)	4 (0.7%)	0.7578
Blood Loss>20%	275 (3.5%)	210 (3.7%)	28 (3.5%)	20 (2.6%)	17 (3.1%)	0.4503
Tension pneumothorax	118 (1.5%)	91 (1.6%)	12 (1.5%)	8 (1.1%)	7 (1.3%)	0.6535
Spine multiple fractures	1078 (13.9%)	734 (13%)	114 (14.1%)	150 (19.8%)	80 (14.6%)	< 0.0001
Spine dens fracture	164 (2.1%)	87 (1.5%)	19 (2.4%)	37 (4.9%)	21 (3.8%)	< 0.0001
Spine compression grade 2 and 3	141 (1.8%)	98 (1.7%)	13 (1.6%)	17 (2.2%)	13 (2.4%)	0.5485
Spine unstable fracture	717 (9.2%)	502 (8.9%)	79 (9.8%)	94 (12.4%)	42 (7.7%)	0.0077
Spinal cord injury	526 (6.8%)	376 (6.7%)	51 (6.3%)	63 (8.3%)	36 (6.6%)	0.3452

TABLE 5.4: INJURY SITE (AIS 3+) BY AGE FOR TRAPPED CASUALTIES

		Age group				
Anatomical Site	**Total**	**16 - 59**	**60 - 69**	**70 - 79**	**80+**	**Significance (p)**
Head	1896 (24.5%)	1528 (27.1%)	135 (16.7%)	139 (18.4%)	94 (17.1%)	< 0.0001
Face	52 (0.7%)	43 (0.8%)	3 (0.4%)	5 (0.7%)	1 (0.2%)	< 0.0001
Thorax	4159 (53.6%)	2945 (52.2%)	438 (54.3%)	430 (56.9%)	346 (63%)	< 0.0001
Abdomen	950 (12.3%)	770 (13.6%)	74 (9.2%)	65 (8.6%)	41 (7.5%)	< 0.0001
Spine	844 (10.9%)	577 (10.2%)	96 (11.9%)	109 (14.4%)	62 (11.3%)	< 0.0001
Pelvic	895 (11.5%)	686 (12.2%)	82 (10.2%)	60 (7.9%)	67 (12.2%)	< 0.0001
Limb	2522 (32.5%)	2028 (35.9%)	232 (28.7%)	164 (21.7%)	98 (17.9%)	< 0.0001

Statistically significant but not clinically significant differences were demonstrated across the physiological and injury-based considerations for self-extrication. The proportion of patients with injuries likely to preclude self-extrication was similar across the age groups (Table 5.5).

Table 5.5: Physiological and injury considerations for potential for self-extrication by age

		Age group				
Parameter	**Total**	**16 - 59**	**60 - 69**	**70 - 79**	**80+**	**Significance (p)**
Systolic BP <90	418 (5.4%)	301 (5.3%)	48 (6.0%)	39 (5.2%)	30 (5.5%)	0.908
GCS 12 or less	1183 (15.3%)	1006 (17.8%)	68 (8.4%)	57 (7.5%)	52 (9.5%)	< 0.0001
Spine AIS3+	844 (10.9%)	577 (10.2%)	96 (11.9%)	109 (14.4%)	62 (11.3%)	< 0.0001
Pelvic AIS 3+	895 (11.5%)	686 (12.2%)	82 (10.2%)	60 (7.9%)	67 (12.2%)	< 0.0001
Limb AIS 3+	2522 (32.5%)	2028 (35.9%)	232 (28.7%)	164 (21.7%)	98 (17.9%)	< 0.0001
None of the above	3208 (41.4%)	2264 (40.1%)	343 (42.5%)	357 (47.2%)	244 (44.4%)	0.079

AIS = Abbreviated Injury Scale, BP = Blood pressure, GCS = Glasgow Coma Score

Discussion

Patients over 80 years old are particularly vulnerable to the negative effects of entrapment following an MVC. Older patients are more likely to have chest and spinal injuries than younger patients - however, the overall rate of spinal injuries in comparison to other likely time dependent injuries remains low. Across the age groups, approximately 40% of patients who were trapped did not have injuries or physiological impairment likely to hinder self-extrication.

Meaning of the study

This study offers fresh insights that are useful for those providing clinical care on scene, planning extrication strategies and supporting clinicians in enabling patients to self-extricate. Injuries of the head, thorax, face and limb are unlikely to benefit from a longer extrication strategy based on movement mitigation when other quicker routes such as self-extrication could be considered; these injuries may be time dependent and the extended time these patients remain in the vehicle will add to excess mortality related to bleeding and hypoxia [248,253]. Gentle patient handling and movement mitigation may help with prevention of clot disruption in abdominal or pelvic injury [220], but these significant injuries often require blood product resuscitation and early access to hospital-based services for identification of injury (CT scan) and treatment (interventional radiology or damage control surgery)[254].

The small increased rate of spinal injuries in older patients may be because of the decreased bone density, muscle and ligament strength and degenerative changes causing narrowing of the spinal canal experienced by the older patient [251]. Recent work has identified that self-extrication results in less movement of the cervical and lumbar spine than other extrication types in healthy volunteers [247]. If these findings can be extrapolated to the injured population, self-extrication may present the best route of egress even for those with suspected spinal injuries.

Patients, and particularly older patients may have occult injuries [255]. As such, predicting a patient's ability to self-extricate is complex. We suggest that self-extrication has significant advantages over more formal alternative extrication techniques and as such should be considered as a route of egress for all patients unless it is clearly impracticable or unachievable. The advantages of self-extrication for the patient include minimal entrapment time (self-extrication is quickest) and minimal movement [247]. For those patients who cannot self-extricate a minimally invasive extrication approach should be used – providing the patient with the necessary support to extricate from the vehicle with minimal cutting / space creation using the principles of gentle patient handling.

Strengths and weaknesses

This is the largest analysis to date of trapped patients injured in MVCs, which allows comparison of injury severity, injury type and outcomes for patients stratified by age.

TARN data may be incomplete, with patients aged over 60 having a lower level of data completeness than younger patients [208]. This study is based upon chronological age – the effects of which are subject to considerable variation between individuals [256]. This study does not specifically report frailty – which is likely to be an important factor both in a patient's resilience to injury and their potential to recover successfully from injury and therefore affect both injury severity and mortality [257].

We have selected pragmatic physiological and injury-based criteria which are likely to affect the ability of a patient to participate in self-extrication. These criteria have not been validated in this setting but provide useful context.

This study is limited in that it does not report non-patient factors relating to the scene of a collision which will affect clinical decision making. We do not report type of vehicle, closing speed, vehicle damage or the use and/or deployment of restraint systems. Importantly we cannot distinguish between patients that are physically trapped and those that are medically trapped following their MVC.

Unanswered questions and future research

Future work should focus on clearly defining patient groups that are not suitable for self-extrication. This may be through prospective data collection of extrication type and patient outcomes, expert consensus, and patient consultation. It is important to distinguish between patients who are physically trapped and those that are medically trapped, and this should be routinely collected on operational and medical data sets considering trapped patients post MVC.

Conclusions

Patients over the age of 80 are more likely to die when trapped following an MVC. Older patients are more likely to have chest and spinal injuries than younger patients - however, the overall rate of spinal injuries remains low across all age groups. Older patients are no more likely to have injuries that would hinder self-extrication than younger patients.

Self-extrication should be considered the primary route of egress for patients of all ages apart from where it is clearly impracticable or unachievable. For those patients who cannot self-extricate a minimally invasive extrication approach should be employed to minimise entrapment time.

Section discussion

This section presents three retrospective cohort studies considering the demographics, injuries and outcomes of trapped and not trapped patients. The groups are compared, and the impact of age and sex considered.

The most important finding of this work is identifying and reporting the difference in outcomes between trapped and not trapped patients [211]. The excess mortality associated with entrapment once known confounders are considered may indicate that quality improvement and/or intervention in this area may lead to a decreased mortality. Correlation is not causation and reducing the rate of entrapment or entrapment time alone will not necessarily lead to improved outcomes in this patient group. The identified association found here is biologically plausible with entrapment foreseeably prolonging time to both prehospital intervention (such as the administration of TXA) or in-hospital treatment of life-threatening injuries (e.g. interventional radiology for non-compressible haemorrage) [258].

A second key finding is the low rate of spinal cord injury and the higher rate of potentially time dependent injuries [211,243,259]. Movement mitigation during extrication takes time and can only benefit those patients with an unstable spinal or established cord injury [141]. As such a very small proportion of patients may see some benefit but the vast majority may suffer harm. This understanding of the incidence of spinal injury will be key in developing and refining evidence-based extrication techniques.

The TARN dataset is limited in its recording of potential confounders; additional datapoints recorded within TARN or the combination of data held by FRS services and the police with TARN may add a degree of fidelity which with further analysis would allow for a deeper understanding of the excess death associated with entrapment. The addition of car type, year of manufacture, patient position within the vehicle, entrapment time and extrication route would all be useful additions [259,260].

TARN and therefore these analyses are limited to data collected in the UK. It is important to validate these findings where possible in other environments. There are significant differences in population factors, road, rescue and health infrastructure, vehicle type and age between lower- and middle-income countries (LMIC) and the UK [1,2]. There is a disproportionate morbidity and mortality in relation to road traffic accidents in LMIC and as such comparative analysis would be invaluable [1].

Longitudinal analysis to understand the excess mortality and morbidity associated with entrapment as and when extrication approaches change will provide an important patient centred safety metric and help in the identification of unintended consequences of any such changes.

Key messages: Section 2

- Trapped patients have more injuries and are more likely to die
- The rate of spinal cord injuries (around which extrication techniques are based) is low (0.7%).
- Female patients are more likely to be trapped than males. Female patients have a higher incidence of spinal and pelvic injuries. Male patients have a higher incidence of face head, chest and abdominal injuries.
- Older people have an excess mortality associated with entrapment.
- Older trapped people have increased but still low rates of spinal injury.
- Older people have a similar potential for self-extrication as younger people.

Section 3

Biomechanics

Section 3 consists of four biomechanical studies assessing the utility of established extrication techniques to deliver movement minimisation. These are powered studies across a range of healthy volunteers. The full range of extrication techniques are considered and compared. A new metric for evaluating cumulative movement is developed and reported. The role of cervical collars in minimising movement in self-extrication is considered and analysed in detail.

This section consists of the following sub-sections:

- Section introduction
- Chapter 6: Nutbeam, T. Fenwick R, May B, Stassen W, Smith JE, Wallis L, Dayson M, Shippen J. The role of cervical collars and verbal instructions in minimising spinal movement during self-extrication following a motor vehicle collision - a biomechanical study using healthy volunteers. *Scand J Trauma Resusc Emerg Medicine* **29**, 108 (2021).
- Chapter 7: Nutbeam, T. Fenwick R, May B, Stassen W, Smith JE, Shippen J. Maximum movement and cumulative movement (travel) to inform our understanding of secondary spinal cord injury and its application to collar use in self-extrication. *Scand J Trauma Resusc Emerg Medicine* **30**, 4 (2022).
- Chapter 8: Nutbeam, T. Fenwick R, May B, Stassen W, Smith JE, Bowdler J, Wallis L, Shippen J. Assessing spinal movement during four extrication methods: a biomechanical study using healthy volunteers. *Scand J Trauma Resusc Emerg Medicine* **30**, 7 (2022).
- Chapter 9: Nutbeam, T. Fenwick R, May B, Stassen W, Smith JE, Bowdler J, Wallis L, Shippen J. Comparison of 'chain cabling' and 'roof off' extrication types, a biomechanical study in healthy volunteers. ***Under peer review; Injury***
- Section discussion

Section introduction

Methods of extrication and time taken

Extrication techniques have evolved with little medical or healthcare input [199]. Movement mitigation (particularly of the spine) has remained the underlying paradigm of extrication as various approaches have evolved. There is no defined or standard nomenclature in use in relation to specific techniques, with a range of authors recommending a variety of approaches, including strategies based upon:

- Patient factors such as physiology [20]
- The route of egress e.g. vertical (out of the roof) and horizontal (out of the door) [30]
- Absolute and relative entrapment - with bespoke extrication solutions [260]
- Extrication principles based on how a patient is entrapped [106,199] and
- Multiple variants based upon patient characteristics such as haemodynamic stability / presence of a spinal injury / physical entrapment [261]

This variation in extrication technique potentially contributes to the limited literature reporting the time taken for 'real world' entrapments. Various time 'targets' for the extrication of patients to be completed vary from 5 minutes through to 30 minutes [19,106]. The benefits of teamwork and inter-agency co-operation in decreasing extrication time are well recognised, though not well evidenced [30,199,262].

Prolonged extrication is defined in the literature as extrication taking >20 minutes [161,195,196,201]. The single prospective real world study in this area found that the median time for extrication was 30 minutes [19].

Self-extrication

Self-extrication is the process by which a patient is instructed to leave their vehicle and completes this with minimal or no assistance from the rescue services[173]. Self-extrication is currently recommended by the Faculty of Pre-Hospital Care of the Royal College of Surgeons of Edinburgh and is featured in Fire and Rescue service national guidance for performing rescue [252]. Despite having featured in this guidance since 2017, translation into casualty care is low, with only 3% of Fire and Rescue services in the UK using self-extrication as a method of extrication on a regular basis [263].

Tool extrication requires the use of cutting tools. The use of such tools causes considerable damage to the vehicles, has significant resource implications and is physically demanding. In many cases tool extrication would require a crew of nine or more firefighters alongside the specialist cutting tools and associated equipment. Tool extrication additionally subjects casualties and rescuers to a real risk of harm.

Self-extrication is significantly quicker than tool extrication methods. Previous work has identified a mean extrication time of 30 minutes for tool extrication [19], whereas self-extrication can normally be completed in less than 60 seconds. While committed to an extrication incident, Fire and Rescue services and the medical response that has attended are not available to respond to other requests for assistance. The time saved both on-scene and in deployment therefore has the potential to relieve some of the significant and increasing service pressures faced by operational staff.

Previous research has demonstrated that self-extrication may be associated with less cervical spine movement than alternative extrication methods. Dixon *et al.* compared extrication methods in healthy volunteers and concluded that instructed self-extrication resulted in less cervical spine movement than using traditional (tool) extrication techniques [181,182]. However, this work has not translated effectively into practice [263].

Cervical collars

The role of cervical spine collars, particularly in conscious trauma patients, is being increasingly questioned; with pre-hospital care practice moving away from the utilisation of collars in all but specialist circumstances (e.g. to allow facial packing in maxillofacial injury). The role of cervical spine collars as an extrication device is virtually unstudied - especially in the setting of self-extrication.

Chain cabling techniques

Extrication practices vary internationally, with the “Scandinavian’ methods involving chain cabling extrications seeming to take less time (in the experimental environment) than those traditionally employed elsewhere in the world [174,175] .

The aim of a chain cabling extrication is to reverse the forces associated with impact by applying chains to pull the vehicle apart and restore its pre-impact structure, thereby rapidly improving access to the casualty. Once the initial phase has been completed the casualty is extricated via the vertical or horizontal route.

Biomechanical assessment of spinal movement

Biomechanics is the study of structure, function and motion [264]. Biomechanical analysis in humans is used to understand and determine the cause of injuries and how such injuries can be minimised. There are a wide range of methods by which data capture to inform biomechanical analysis can occur.

Movement at the spine can be measured in a number of ways (e.g. video capture, force platforms, strain / force gauges) – not all of which are practical in the setting of the dynamic movement of extrication within a vehicle.

Many of the imaging techniques (X-ray, CT and MRI have been widely used) are not feasible to assess spinal movement outside a static healthcare environment [265].

Goniometers and inclinometers developed for commercial use have been used to measure cervical spine movement in other settings [266,267] and these devices are suitable for the laboratory environment but have limited ability to record complex movements. Furthermore, their reliance on manual measurement limits their application in recording dynamic movements.

The Cervical Range of Motion (CROM) device has proven utility in measuring rotational movement at the cervical spine [268]. However, its reliance on gravity limits its application to upright patients and as such is unsuitable for use in the extrication setting [269].

Other researchers in the field of biomechanical analysis of extrication have used variations on video motion technology and infra-red motion capture technology [177,178]. This technology is useful as it enables repeated measurements of movement in laboratory environments in a non-invasive and relatively time and resource efficient manner. The key limitation of this technology is that it requires an uninterrupted line of sight between at least two of the motion capture camera and ‘markers’ or ‘tracers’ placed on the subject’s spine. This uninterrupted line of sight requirement can be partially mitigated by using multiple cameras – however, in the setting of extrication research, this limitation prevents data capture from the whole spine. In addition, infrared or video capture technology necessitates the use of ‘mock up’ vehicles which have been altered to preserve line of sight – this leads to concerns over the external validity of findings to real world application.

The inertial motion unit (IMU) uses relatively new technology that does not rely on line of sight for data capture. The IMU sensor contains three each of the following: orthogonal linear accelerometers, orthogonal rate gyroscopes and orthogonal magnetometers. The accelerometers measure the acceleration applied to the device itself once the force of gravity is excluded, the gyroscopes measure angular velocity, and the magnetometers provide data which allows the sensor to align and report relation to the Earth's magnetic fields. 'Sensor fusion' software combines the data from multiple IMU's to produce a complete picture of the device's orientation and movement. These units can be placed on the subject's anatomical area of interest – and when combined with a biomechanical computer model can be used to accurately track movement [270]. The IMUs are not affected by sunlight, are reasonably robust and can be used outside of the laboratory environment. IMUs have been demonstrated to be comparable with optical methods of movement tracking, further enabling their utility for biomechanical analysis [271,272].

Application of biomechanical principles to extrication

The increasing availability of small, portable and cost-efficient biomechanical assessment devices allowed researchers to evaluate practices in a meaningful way in simulated settings [269]. The choice of device to monitor movement will depend upon the requirements of the setting, which movements need to be captured and any special constraints.

As a result of the availability of such devices, researchers began to investigate and challenge existing extrication practices. Bucher *et al.* found that utilising a KED (Kendrick extrication device) resulted in less spinal movements in patients with a normal body mass index (BMI) but increased spinal movement in obese patients [176]. Shafer *et al.* performed a pilot study that concluded that allowing an individual to exit the car under his own volition (self-extrication) with cervical collar in place may result in the least amount of motion compared to exiting with paramedic assistance [177]. Dixon *et al.* identified that conventional extrication techniques record up to four times more cervical spine movement during extrication than controlled self-extrication [181,182].

There are a number of challenges to the translation of these findings into changes in extrication practice:

- They are often small, considered 'pilot' work and don't reach definitive or translatable conclusions

- They often answer a single question rather than providing a solution to the challenge of extrication of patients as a wider group
- Extrication has developed without medical input, so considerable engagement and translational work will be required to influence established paradigms

The four papers presented in this section provide new knowledge in relation to the movements of the spine during extrication. They are unique and offer additional internal and external validity over previous studies. This is achieved through additional methodological rigour: adequately powering the studies off a clinically important outcome and recruiting a range (age / sex / BMI) of volunteers to participate in the study.

The next chapters which make up the remainders of this section consist of four original papers which are reproduced in full but formatted to provide consistency throughout this thesis. This section ends with a discussion of the contributory chapters and relates their findings and outcomes to the thesis as a whole.

Chapter 6: The role of cervical collars and verbal instructions in minimising spinal movement during self-extrication following a motor vehicle collision - a biomechanical study using healthy volunteers

Declaration from author and co-authors

The following co-authors contributed to the publication: Fenwick R, May B, Stassen W, Smith JE, Wallis L, Dayson M, Shippen J,

Contributions of the authors were as follows: All authors contributed to the conception and study design. Logistics, data collection and reporting by JS, BM, MD, RF & TN. Initial analysis by TN with clinical interpretation by TN, RF, JS, LW and WS. All authors have contributed to and approved the manuscript.

The extent of contributions from each person are as follows:

- TN: 55%
- RF: 12.5%
- BM: 7.5%
- WS: 7.5%
- JES: 5%
- LW: 2.5%
- MD: 2.5%
- JS: 7.5%

Given the large number of co-authors, the principal investigator and the supervisor hereby sign for approval on behalf of the group, in accordance with the UCT Doctoral Degrees Board guideline titled, “GUIDELINES FOR THE INCLUSION OF PUBLICATIONS IN A DOCTORAL THESIS.”

	25 July 2022
Tim Nutbeam	Date
	25 July 2022
Willem Stassen	Date

Abstract

Background

Motor vehicle collisions account for 1.3 million deaths and 50 million serious injuries worldwide each year. However, the majority of people involved in such incidents are uninjured or have injuries which do not prevent them exiting the vehicle. Self-extrication is the process by which a casualty is instructed to leave their vehicle and completes this with minimal or no assistance. Self-extrication may offer a number of patient and system-wide benefits. The efficacy of routine cervical collar application for this group is unclear and previous studies have demonstrated inconsistent results. It is unknown whether scripted instructions given to casualties on how to exit the vehicle would offer any additional utility.

The aim of this study was to evaluate the effect of cervical collars and instructions on spinal movements during self-extrication from a vehicle, using novel motion tracking technology.

Methods

Biomechanical data on extrications were collected using Inertial Measurement Units on 10 healthy volunteers. The different extrication types examined were: i) No instructions and no cervical collar, ii) No instructions, with cervical collar, iii) With instructions and no collar, and iv) With instructions and with collar. Measurements were recorded at the cervical and lumbar spine, and in the anteroposterior (AP) and lateral (LAT) planes. Total movement, mean, standard deviation and confidence intervals are reported for each extrication type.

Results

Data were recorded for 392 extrications. The smallest cervical spine movements were recorded when a collar was applied and no instructions were given: mean 6.9mm AP and 4.4mm LAT. This also produced the smallest movements at the lumbar spine with a mean of 122mm AP and 72.5mm LAT.

The largest overall movements were seen in the cervical spine AP when no instructions and no collar were used (28.3mm). For cervical spine lateral movements, no collar but with instructions produced the greatest movement (18.5mm). For the lumbar spine, the greatest movement was recorded when instructions were given and no collar was used (153.5mm AP, 101.1mm LAT).

Conclusions

Across all participants, the most frequently occurring extrication method associated with the least movement was no instructions, with a cervical collar in situ.

Background

Motor vehicle related trauma is common – accounting for 1.3 million deaths and 50 million serious injuries per year worldwide [1]. The United Nations (UN) Sustainable Development Goals include a target to halve all road deaths and injuries by 2020 [2]. Following a Motor Vehicle Collision (MVC) up to 40% of casualties will be trapped and require extrication - these casualties have an excess morbidity and mortality [67,69,161,165,195,196,201,211].

A small proportion of casualties will remain in their vehicle following an MVC as they require disentanglement from the wreckage (physical entrapment) by rescue services [173].

These extrications require the use of cutting and spreading tools. The use of such tools may cause considerable additional vehicular damage, has significant resource implications (both human and equipment), is physically demanding and additionally subjects casualties and rescuers to a real risk of harm [252].

Other casualties may not be able to leave their vehicle due to the severity of the injuries that they have sustained. In trapped casualties with major trauma, chest injuries are the most common severe injury (abbreviated injury scale >= 3) followed by limb and then head injuries. Unstable spinal injury or spinal cord injury are infrequent [211].

Most people involved in MVCs will be uninjured or have injuries which do not prevent them exiting the vehicle. There will also be cases where those with significant injuries may be able to exit the car without formal extrication by rescue services [173].

Self-extrication is the process by which a casualty leaves their vehicle (with or without instructions) and completes this with minimal or no assistance from the rescue services [273]. Self-extrication is currently recommended by the Faculty of Prehospital Care of the Royal College of Surgeons of Edinburgh and is featured in United Kingdom (UK) Fire and Rescue Services (FRS) national guidance for performing rescues [252]. Despite having featured in this guidance since 2017, translation into practice is low, with only 3% of FRS in the UK using self-extrication on a regular basis [263].

Self-extrication is significantly quicker than tool extrication methods. Previous work has identified a mean extrication time of 30 minutes for tool extrication [19], whereas self-extrication can normally be completed in less than 60 seconds. While committed to an extrication incident, both the rescue services and the medical response that has attended are not available to respond to other requests for assistance. The time saved both on-scene and in deployment therefore has the potential to relieve some of the increasing service pressures faced by operational staff.

Fire and Rescue service guidance indicates that even minimal movement of the spinal column during extrication may be disastrous for casualties, by significantly exacerbating a spinal injury: "*with an unstable fracture, displacement of as little as one millimetre may be enough to compress, pinch or shear the spinal cord. This damage may make the difference between normal function and permanent paralysis, therefore it is imperative that no further motion occurs in an unstable spine…"* [11]. Guidance also indicates that spinal injury should be assumed to have occurred in the vast majority of MVCs: "*the presence of spinal injury must be assumed with any sudden acceleration or deceleration accident"* [11].

The role of cervical collars, particularly in conscious trauma casualties, is being increasingly questioned, with prehospital care practice moving away from the utilisation of collars in all but special circumstances (e.g. to allow facial packing in maxillofacial injury) [99,100,274,275]. These conflicting analyses suggest that the optimal role of cervical collars as an extrication device remains unclear, particularly in the setting of self-extrication [179,180,182].

The aim of this study is to evaluate the role of both cervical collars and instructions, in relation to cervical and lumbar spinal movements, for casualties undertaking self-extrication from a vehicle, by using motion tracking technology.

Methods

This study is a biomechanical analysis using healthy volunteers, comparing cervical and lumbar spine movement during four types of self-extrication. The extrication types are: i) No instructions and no cervical collar, ii) No instructions, with cervical collar, iii) With instructions and no collar, and iv) With instructions and with collar.

Participants: Ten healthy volunteers were recruited to participate in this study from participating FRS centre support roles. Participants had no previous knowledge of extrication, had no back or neck conditions that may be exacerbated by extrication and had a body mass of less than 100kg. Participants were briefed on the study, had access to a participant information sheet in advance and completed written informed consent prior to participation.

Data collection: Each participant's height and weight were recorded prior to being fitted with the Inertial Measurement Unit (IMU) (Xsens Awinda). IMU's are biomechanical analysis devices which include three orthogonal linear accelerometers, three orthogonal rate gyroscopes and three orthogonal magnetometers. By attaching inertial measurement unit (IMU) sensors to each of the major segments of the body, the posture can be measured and, together with a foot contact model and biomechanical model, the positioning of the subject can be recorded [270]. The accuracy of IMU based kinematic and kinetic measurements have been shown to be comparable with optical tracking methods and has been validated for such applications therefore enabling their utilisation within clinical analysis [271,272]. In this case, the IMU sensor was attached to the head using a headband. The thorax was assumed to be rigid and sensors were positioned over the clavicle notch on the sternum and over each scapula using a tight-fitting elastic vest. A sensor was positioned on the sacrum by attaching the sensor to shorts using hook-and-loop fastening, to prevent upward travel, and securing the sensor against the body with an elastic belt. Orientation data were collected from each sensor via a wi-fi link and sampled at a rate of 60Hz.

Where collars were required, Laerdal Stiff Neck collars were used, and these were fitted by a member of the study team trained in their use in accordance with manufacturer guidance. The verbal instructions for extrication were taken from the work of Dixon *et al.* and can be found in Box 6.1; these instructions were delivered by a trained member of the study team [182].

A power calculation was performed to determine the sample size required for this study. The existing literature in this and related fields was searched to identify a suitable minimally clinical important difference (MCID) for spinal movement in the context of prevention / minimisation of secondary injury. A MRI study reported a mean difference of 2.7mm between spinal canal space in patients with and without cord injury in the context of bony spinal injury [276]. Despite the significant limitations of how this value was derived, previous studies of extrication recommend using this value as the MCID to power biomechanical trials of extrication [182]. This trial was powered using means and standard deviations derived from pilot data collected by this study group. The power calculation was based on finding an anterior-posterior translational movement at the cervical spine of 2.7mm with a significance level of 1% and a power of 90%, giving a sample size of 47 per group.

Each of the ten participants repeated each of the four types of self-extrication 10 times giving a total of 100 extrications for each type and 400 extrications across the study. Data were excluded from analysis if a sensor became dislodged or data capture failed.

The vehicle type was pre-specified as a 5-door hatchback (2018 Nissan Leaf), the commonest vehicle type on UK roads [277].

The IMU directly measures the segmental orientations from which relative motions can be calculated and reported by assuming the relative rotations of adjacent vertebrae across the lumbar and cervical region are constant. Maximum excursions (movement from a hypothetical midline) were calculated for anterior/ posterior (AP) movement of the cervical spine and lumbar spine, and lateral (Lat) movement of the cervical spine and lumbar spine. The travel of a body segment is defined as the cumulative total of the magnitude of incremental displacements.

Data were captured and analysed using the Biomechanics of Bodies (BoB, Bromsgrove, UK) software interface [278] before being exported to Excel (Microsoft v. 16.9) and SPSS (IBM v. 25, Armonk NY) for further analysis and reporting. Total excursions, standard deviation and confidence intervals are reported for each extrication type. P values were calculated using a two tailed t-test comparing each extrication method with Dixon's standard (self-extrication with instructions and no collar).

The study protocol was reviewed and approved by the University of Coventry Research Ethics Committee (reference number P88416).

Results

Data from a total of 392 extrications were successfully collected for analysis (98% data capture success rate). Seven of the ten participants were female, with a mean age across all of the participants of 39 years (range 21-59) and BMI of 25.1 (range 19-29).

The results are summarised in Tables 6.1-2 and Figures 6.2-5. The mean movement across the four extrication types was 16.2mm (Cervical AP), 11.5mm (Cervical Lat), 133.4mm (Lumbar AP) and 87.9mm (Lumbar Lat). Cervical roll was 21.0^{o}, cervical pitch 29.9^{o} and cervical yaw 32.1^{o}. Lumbar roll was 32.7^{o}, lumbar pitch 42.7^{o} and lumbar yaw 40.4^{o}.

TABLE 6.1: PARTICIPANT DEMOGRAPHICS, EXTRICATIONS AND MEAN AP MOVEMENT

Participant	Age	Weight (kg)	Height (cm)	BMI	Sex	Extrications	Mean AP cervical movement mm (SD)	
1	59	85	175	27.8	M	39	22.8	(2.6)
2	27	55	163	20.7	F	39	25.2	(1.9)
3	39	74	168	26.2	F	39	26.0	(2.7)
4	28	55	167	19.7	F	40	22.2	(7.00)
5	52	84	180	25.9	M	41	17.8	(2.2)
6	38	59	157	23.9	F	39	23.9	(2.2)
7	45	79	180	24.4	M	37	30.0	(3.7)
8	53	68	153	29.0	F	38	21.3	(2.2)
9	28	56	152	24.2	F	40	16.8	(2.6)
10	21	77	163	29.0	F	40	18.5	(3.2)
MEAN:	39	69.2	165.8	25.1	M:F, 3:7	Total: 392	22.5	(5.1)

Table 6.2: Means, standard deviations and p values

	With instruction no collar		With instruction with collar			No instruction no collar			No instruction with collar		
	MEAN	**STDEV**	**MEAN**	**STDEV**	**Significance (p)**	**MEAN**	**STDEV**	**Significance (p)**	**MEAN**	**STDEV**	**Significance (p)**
Cervical A/P [mm]	22.5	5.1	***7.0***	***2.7***	***<0.001***	28.3	6.9	<0.001	***7.0***	***4.2***	***<0.001***
Cervical Lat [mm]	18.5	6.3	6.3	2.1	<0.001	17.0	4.6	0.02	***4.4***	***1.9***	***<0.001***
Cervical roll [^{O}]	33.9	13.0	10.8	4.0	0.2	33.3	17.5	0.36	*9.8*	*8.4*	*0.15*
Cervical pitch [^{O}]	42.7	9.2	13.2	5.3	<0.001	50.5	13.4	<0.001	***13.0***	***7.3***	***<0.001***
Cervical yaw [^{O}]	49.3	20.3	15.0	9.0	<0.001	54.6	19.3	0.061	***9.5***	***5.0***	***<0.001***
Lumbar A/P[mm]	153.5	35.2	135.8	35.3	<0.001	122.4	27.7	<0.001	***122.0***	***19.1***	***<0.001***
Lumbar Lat [mm]	101.1	22.5	102.5	35.4	0.54	75.7	28.0	<0.001	***72.5***	***27.4***	***<0.001***
Lumbar roll [^{O}]	33.0	6.4	36.3	13.3	0.012	***29.0***	***10.2***	***0.001***	32.3	13.0	0.64
Lumbar pitch [^{O}]	49.1	9.6	43.0	10.9	<0.001	39.7	9.3	<0.001	***39.1***	***7.7***	***<0.001***
Lumbar yaw [^{O}]	46.9	11.5	50.0	17.2	0.46	***31.0***	***7.8***	***<0.001***	**33.7**	**10.9**	***<0.001***

Bold italics = extrication values with statistically significant smallest movement

For the cervical spine, the smallest overall movements were recorded when a collar was applied and no instructions were given (6.9mm AP and 4.4mm LAT). These were also the conditions producing the smallest movements at the lumbar spine (122mm AP and 72.5mm LAT).

FIGURE 6.2: MEAN EXCURSION AND CONFIDENCE INTERVALS FOR ANTERIOR-POSTERIOR MOVEMENT AT THE CERVICAL SPINE

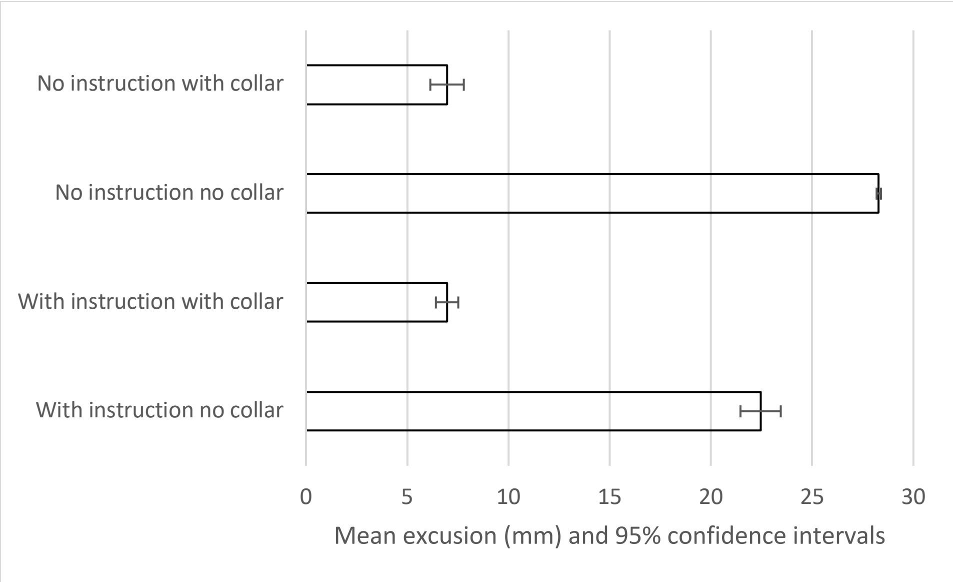
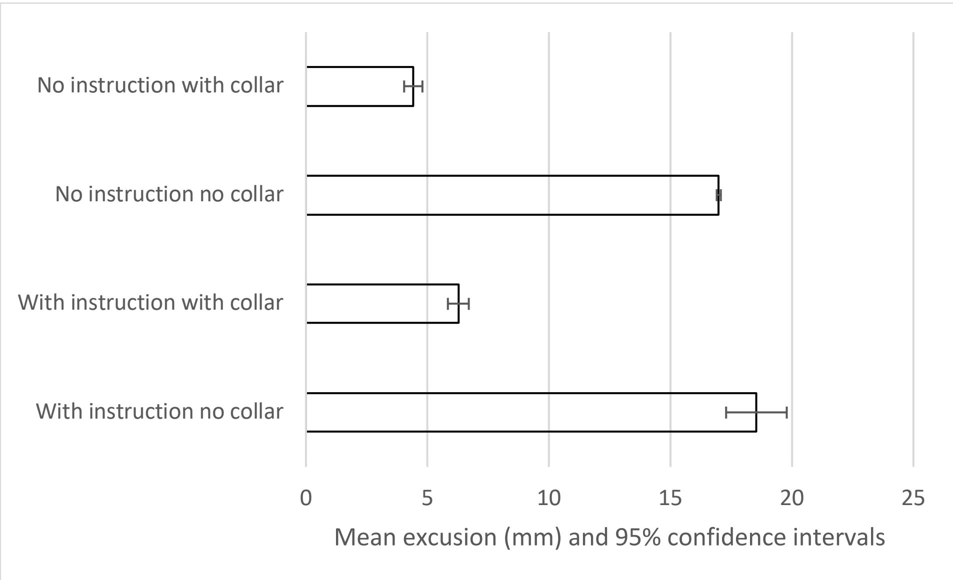


FIGURE 6.3: MEAN EXCURSION AND CONFIDENCE INTERVALS FOR LATERAL MOVEMENT AT THE CERVICAL SPINE



The largest overall movements were seen in the cervical spine AP when no instructions and no collar were used (28.3mm). For cervical spine lateral movements, no collar but with instructions produced the greatest movement (18.5mm). For the lumbar spine, the greatest movement was also recorded with no collar but with instructions (153.5mm AP and 101.1mm LAT).

FIGURE 6.4: MEAN EXCURSION AND CONFIDENCE INTERVALS FOR ANTERIOR-POSTERIOR MOVEMENT AT THE LUMBAR SPINE

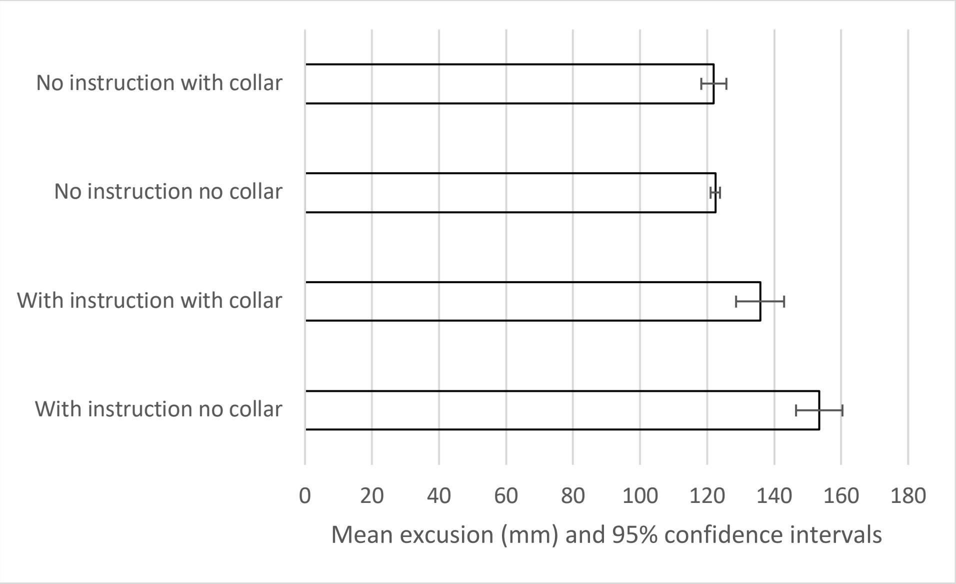


FIGURE 6.5: MEAN EXCURSION AND CONFIDENCE INTERVALS FOR LATERAL MOVEMENT AT THE LUMBAR SPINE

When the data were disaggregated by gender similar findings were found for males and females, with application of a collar and no instructions leading to the smallest movements at the cervical and lumbar spine in both groups.

Discussion

This is the first biomechanical analysis of different types of self-extrication published to date, reporting both cervical and lumbar movements as well as providing additional details of excursion and rotation. This is also the first study which allows direct comparison of the effect of instructions and cervical collars on spinal movement. The use of a collar and no instructions resulted in the smallest movement of the cervical and lumbar spine during self-extrication.

Instructions: Commonly people remain in cars following MVCs as a result of concerns about movement exacerbating potential spinal injury. Delivery of instructions would require the presence of trained personnel (rescue service or clinical) on scene or a telecommunications surrogate (e.g. via mobile telephone). If instructions are not beneficial, as suggested by this study, then this would potentially release clinical and operational personnel to other tasks and empower policy that encourages potential casualties to leave their car before the arrival of clinical or operational services.

The finding of increased spinal movement with instructions was unexpected. Dixon *et al.* utilised instructions for all of their self-extrications, which were also adopted for Haske's single participant study [180,182]. Engsberg *et al.* did not provide instructions to their participants [178]. Gabreli *et al.* compared the use of instructions provided in video and verbal explanatory format prior to the subjects (all young men less than 30 years of age) attempting self-extrication – they found that instructions reduced movement in the sagittal (AP) plane (other movements were not tested / analysed) at the cervical spine [179]. No previous studies have considered movement at the lumbar spine. Within our study we attempted to maximise external validity by using participants unfamiliar with extrication and using direct verbal instruction as would be delivered by a member of a rescue team at the scene of an incident.

We suggest that the smaller movements found when no instructions were given was a result of subjects finding their own 'route' to leave the vehicle, resulting in a more natural, comfortable extrication. This 'naturalness' perhaps explains the very narrow confidence interval found for results for no-collar and no instructions across all translation movements (Figures 6.2-5). If this hypothesis is correct, we would expect the difference in movement between instructions and no instructions to be larger in a patient's own vehicle, where familiarity and well-practiced egress could lead to smaller movements. We did not investigate the effect of variations in instructions but utilised the instructions previously produced by Dixon *et al.* – refinement of such instructions could lead to decreased spinal movement and is a consideration in planning further research in this area.

Cervical collar: Cervical collars are carried on all FRS appliances in the UK. They are commonly applied to casualties whilst still in their car and remain in situ throughout extrication. If collars are not required in casualties suitable for self-extrication this would have significant implications for the time in their clinical course that casualties may be asked to attempt self-extrication. This could mean that some casualties could be asked to attempt self-extrication at initial call to the Emergency Services. Such a finding would also have significant implications for recommendations to bystander / buddy care at the scene of an MVC. In our study there was a strong association between collar use and decreased cervical spinal movement ($p<0.001$); this finding is in keeping with the intended purpose of such devices and is consistent with previous work [178,180]. It is contrary to the findings of Dixon *et al.* who identified a small, mean increase in movement associated with collars when degrees of anterior–posterior, medial–lateral and rotational movement were combined [182]. The difference identified by Dixon was small, not present in all of the participants studied and the confidence intervals between the two groups overlapped. There has been increasing challenge to the routine use of cervical collars in prehospital care [99]. The purpose of a cervical collar is to minimise movement and as such stop an unstable fracture from causing secondary avoidable cord damage. A majority of the biomechanical analysis in this area uses healthy volunteers or cadavers and as a result it remains unclear that using a collar effectively reduces movement when an unstable cervical spine injury is present [279].

As might be expected, in our study the cervical collar did not consistently reduce movement at the lumbar spine.

Movement in the context of spinal cord injury: Significant force is required to cause unstable spinal fracture or cord injury. Such forces would normally be associated with significant movement, movement that is likely to be maximal at the point of energy transfer. Despite the potential biomechanical implausibility of small additional movements causing further cord injury, extrication strategies and rescue services approach are focused on movement minimisation and the prevention of secondary injury [11].

Limitations: This study has a number of limitations. By definition, our volunteers were healthy and without spinal pathology. They were not subjected to MVCs, recent spinal trauma and did not have unstable (or other) spinal injuries. Our volunteers did not have distracting injuries, intoxication, confusion, pain-relief administered, or the psychological impact of a real MVC.

This limits application of our results to the significantly injured patient population. In real patients with spinal injuries, the movements may be larger in those with unstable injuries or reduced due to the pain and muscular spasm that frequently co-exists with an acute injury.

This study aimed to maximise external validity by utilising volunteers with no knowledge of the process of extrication, a mix of males and females and a range of weights, heights and BMI's. There was no discernible association between each of these factors and spinal movement. In this context, variation of self-extrication technique by patient sex, age, weight, height or BMI cannot be recommended on the basis of this study, but could be considered in further research. The order in which participants progressed through the study arms was delivered to minimise learning, particularly in relation to the verbal instructions. Learning may, however, have occurred as the participants progressed through the study and this may affect the internal validity of the study. Likewise, the potential effect of participant fatigue on our results cannot be ruled out.

The study vehicle was the same for all volunteers and was not modified but was not one the participants were familiar with and it is possible that familiar vehicles would be associated with different extrication characteristics compared to our test vehicle. There may also be variation in results for vehicles with inherently different structural characteristics, for example, 4x4 type vehicles or low-riding sports vehicles.

Interpretation in a clinical context: The majority of casualties involved in MVCs are uninjured or have only minor injuries it is this subgroup in which self-extrication is the preferred route of extrication and which has the most similarities to our healthy volunteers [211]. There are several potential advantages of self-extrication over tool extrication including decreased time, decreased resource utilisation and less risk to the patient and rescuer. Within the inherent limitations of this study, this work helps us to understand self-extrication in the context of spinal movement minimisation. When a patient is suitable for self-extrication (very few casualties with unstable injuries have occult injuries [99], instructions are unnecessary, could be counter-productive and should not be delivered. In services which use collars, these may be applied to facilitate extrication and then removed once the extrication is complete to minimise any potential complications. Further work is needed in this area to understand the movements associated with application of a collar to a patient in a car and the benefits and harms of collars in this patient group at the various stages of their patient journey.

Previous researchers have concluded that self-extrication is associated with smaller movements at the cervical spine than other methods of extrication, which normally involve being physically lifted from the vehicle by rescue service personnel on to a board or a scoop [179,182]. Trapped casualties have an excess mortality, and many of the injuries they suffer are time critical [211]. As such, the benefits and harms of current extrication techniques need to be carefully considered in the context that in all likelihood the current approach is not achieving the intended therapeutic goals in terms of movement minimisation and are potentially contributing to excess morbidity and mortality.

Future research: This should aim to answer the questions of which casualties should self-extricate, whether the principles identified here can be applied to other motor vehicles and the real-world resource, health economic and clinical benefits (or otherwise) of the adoption of self-extrication as the principle route of extrication for appropriate casualties following MVCs. Additional biomechanical studies should be designed to characterise the movement associated with in-car collar application and analysis of other commonly used extrication techniques, including those who cannot self-extricate.

Future research is needed to define which casualties may benefit from current movement minimisation techniques and furthermore engage with casualties and subject matter experts to identify a balanced solution to the problem of casualties trapped in vehicles following MVCs.

Conclusion

In this study of healthy volunteers, self-extrication with no instructions but with a collar resulted in the smallest spinal movement of the four self-extrication approaches used.

When a casualty is suitable for self-extrication, the instructions used in this study should not be used and a simple instruction to leave the vehicle delivered. In services which use collars, these may be applied to minimise spinal movement during extrication.

It is unlikely that the movement minimisation focus of current extrication techniques achieves its therapeutic goal and may contribute to the excess mortality of casualties who are trapped. The harms and benefits of current extrication strategies need careful consideration in this context.

Box 6.1: Instructions for Self-Extrication

Step 1	'Do you understand what we are asking you to do?' Try and keep your head as still as possible. Stop at any time if you feel pain or strange sensations in your body.
Step 2	Slowly move your right foot and place it on the ground outside the car.
Step 3	Using the steering wheel for support pull yourself forward.
Step 4	Keep your left hand on the steering wheel and place your right hand on the edge of the seat behind you.
Step 5	Turn slowly on your seat to face the outside, your left leg should follow when ready but remain seated.
Step 6	With both feet flat on the floor stand straight up using your arms for balance.
Step 7	Take two steps away from the car.

Chapter 7: Maximum movement and cumulative movement (travel) to inform our understanding of secondary spinal cord injury and its application to collar use in self-extrication

Declaration from author and co-authors

The following co-authors contributed to the publication: Fenwick R, May B, Stassen W, Smith JE, Shippen J.

Contributions of the authors were as follows: All authors contributed to the conception and study design. Logistics, data collection and reporting by JS, BM, RF & TN. Initial analysis by TN with clinical interpretation by TN, RF, JS, and WS. All authors read and approved the final manuscript

The extent of contributions from each person are as follows:

- TN: 55%
- BM: 10%
- JES: 5%
- RF: 12.5%
- WS: 7.5%
- JS: 15%

Given the large number of co-authors, the principal investigator and the supervisor hereby sign for approval on behalf of the group, in accordance with the UCT Doctoral Degrees Board guideline titled, “GUIDELINES FOR THE INCLUSION OF PUBLICATIONS IN A DOCTORAL THESIS.”

	25 July 2022
Tim Nutbeam	Date
	25 July 2022
Willem Stassen	Date

Abstract

Background

Motor vehicle collisions remain a common cause of spinal cord injury. Biomechanical studies of spinal movement often lack “real world” context and applicability. Additional data may enhance our understanding of the potential for secondary spinal cord injury. We propose the metric ‘travel’ (total movement) and suggest that our understanding of movement related risk of injury could be improved if travel was routinely reported. We report maximal movement and travel for collar application in vehicle and subsequent self-extrication.

Methods

Biomechanical data on application of cervical collar with the volunteer sat in a vehicle were collected using Inertial Measurement Units on 6 healthy volunteers. Maximal movement and travel are reported. These data and a re-analysis of previously published work is used to demonstrate the utility of travel and maximal movement in the context of self-extrication.

Results

Data from a total of 60 in-vehicle collar applications across three female and three male volunteers was successfully collected for analysis. The mean age across participants was 50.3 years (range 28–68) and the BMI was 27.7 (range 21.5–34.6). The mean maximal anterior-posterior movement associated with collar application was 2.3mm with a total AP travel of 4.9mm. Travel (total movement) for in-car application of collar and self-extrication was 9.5mm compared to 9.4mm travel for self-extrication without a collar.

Conclusion

We have demonstrated the application of ‘travel’ in the context of self-extrication. Total travel is similar across self-extricating healthy volunteers with and without a collar.

We suggest that where possible ‘travel’ is collected and reported in future biomechanical studies in this and related areas of research. It remains appropriate to apply a cervical collar to self-extricating casualties when the clinical target is that of movement minimisation.

Background

MVCs remain a common cause of spinal cord injury [280]. Following an MVC some patients may be able to self-extricate from the damaged vehicle whereas others will need the assistance of the rescue services.

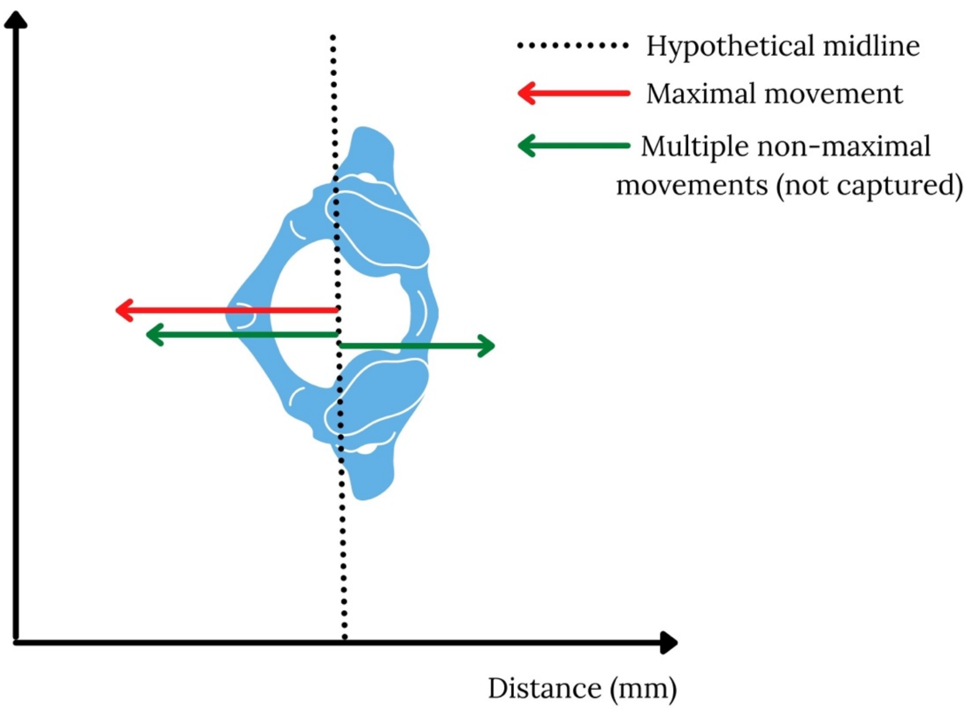
The techniques most frequently utilised by rescue services (e.g. roof removal) have been developed and adopted based upon the principles of movement minimisation and mitigation[19]. This movement focus originates from the understanding that post-injury movements in patients with unstable spinal injuries may exacerbate primary injuries and cause avoidable secondary injury [11]. Whilst some movement is inevitable, the "acceptable" level of spinal movement following an injury is unknown, with prehospital and rescue services often working on the premise that smaller movements are less likely to cause secondary injury than larger movements [182,281].

Biomechanical studies of spinal movement often lack "real world" context and applicability [269]. Many of the inherent limitations of such studies are both ethically and practically challenging to resolve. Challenges include the unsuitability of data collection technology to operate seamlessly to collect 'real-world' data, logistical and ethical concerns associated with using cadaveric models and the inappropriateness of this area of study to the use of an animal model. Despite these challenges, there are practical additional data which can be gleaned from biomechanical studies of healthy volunteers which will be useful to clinicians and those influencing policy in making informed decisions and best judgements in this complex area.

Additional data may enhance our understanding of the potential for secondary spinal cord injury. A variety of biomechanical analysis techniques have been utilised in the study of extrication, episodes of patient care involving the movement of at-risk patients and the effectiveness of immobilisation devices such as cervical collars [180,182,269,281]. These biomechanical studies report maximal movement at the cervical spine and utilise this value as a surrogate of the risk of secondary injury. Understanding and reporting maximal movement is appropriate in this context and it is rational that more movement may cause more injury. We suggest that our understanding of the movements during a particular technique could be deepened and therefore a greater appreciation of movement related risk of injury could be improved if all movements during a particular technique or patient movement were understood and reported.

Secondary spinal cord trauma can be caused by direct damage to the cord itself, (with larger movements expected to cause more damage) and indirect damage to the cord through the initiation or exacerbation of inflammatory processes (which lead to swelling and cord compression) [282]. Similar to many musculoskeletal pathologies a wide range of movements, not just maximal movements, may contribute to the degree of inflammation and / or injury [283]. As such understanding non-maximal movements (particularly repeated movements) will enable a deeper understanding of the effectiveness of spinal movement mitigation and minimisation in relation to its potential to cause secondary cord injury (Figure 7.1).

FIGURE 7.1: REPRESENTATION OF MAXIMAL MOVEMENTS WHICH ARE CAPTURED AND REPORTED IN CURRENT BIOMECHANICAL MODELS OF SPINAL MOVEMENT VS NON-MAXIMAL MOVEMENTS THAT ARE NOT



In addition, it is important to understand the movement associated with the application of an immobilisation device or movement minimisation device under study (in this case we use the example of the "in-car" application of a cervical collar). Previous work in this area has considered the value of a collar during extrication [178,179,182,281]. Self-extrication is where a patient exits from the vehicle following an MVC without assistance. Previous data is conflicting on the value of collars during extrication – with most data favouring the application of cervical collars in minimising maximal movement at the cervical spine during self-extrication. Previous studies have not considered the movement associated with application of a cervical collar whilst a patient remains in the vehicle [178,179,182,281].

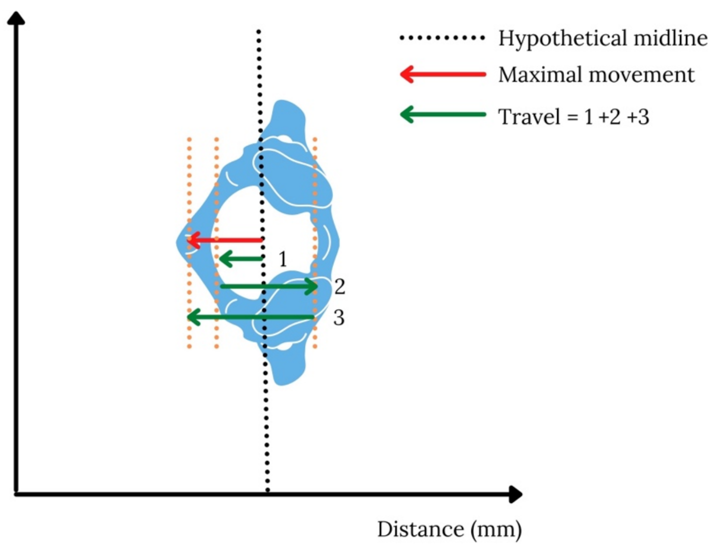
This study will: i) Propose the novel metric of "travel" (cumulative movement) (Box 7.1) ii) Provide data on the movement associated with "in car" application of a cervical collar iii) Use cervical collar application and subsequent self-extrication to demonstrate the utility of 'travel'.

Box 7.1: Travel

Additional data on movement may be useful when considering the likelihood of a movement or procedure leading to avoidable secondary spinal cord injury. We propose that cumulative movement or "travel" may offer utility in this context.

Travel is the total cumulative movement during the procedure or process and is calculated using the sum of all the incremental movements irrespective of whether the movement is in the positive or negative direction.

Figure 7.2: Maximal Movement and Travel



Methods

We undertook an experimental biomechanical study which considers spinal movement at the cervical spine when a cervical collar is applied "in car" prior to an extrication attempt.

Participants: Six healthy volunteers were recruited to participate in this study. The volunteers had no previous knowledge of extrication, had no back or neck conditions that may be exacerbated by extrication and had a mass of less than 100kg. Participants were recruited through local volunteer networks and were not known to the investigating team. Participants were briefed on the study, had access to a participant information sheet in advance and completed written informed consent prior to participation.

Data Collection: Each participant's height and weight were recorded prior to being fitted with the Inertial Measurement Unit (IMU) (Xsens Awinda; Xsens Technologies B.V., Enschede, Netherlands). The characteristics of IMUs and their suitability for extrication research have been described elsewhere [281]. The IMU sensor was attached to the head using a headband. Sensors were positioned over the clavicular notch on the sternum, and over each scapula using a tight-fitting elastic vest. Orientation data were collected from each sensor via a wi-fi link and sampled at a rate of 40Hz. The vehicle type was pre-specified as a 5-door hatchback as this represents the commonest vehicle type on UK roads [277]. The vehicle used was a 2010, Peugeot 206.

Application of collars: The Laerdal (Laerdal Medical Corp., Stavanger, Norway) Stiff Neck collars were fitted by one of two members of the study team trained in their use in accordance with manufacturer guidance. Data were collected for 10 applications of the cervical collar for each of the 6 participants (total 60 collar applications). Participants were not wearing any clothing which would hinder collar application and long hair was tied up.

Analysis: The IMU directly measures the segmental orientations from which relative motions can be calculated and reported, by assuming the relative rotations of adjacent vertebrae across the cervical region are constant. Maximum excursions (movement from a hypothetical midline) were calculated for anterior/posterior (AP) and lateral (Lat) movement of the cervical spine. In addition to reporting maximum excursions (the single largest movement) we report “travel” - the cumulative total of all movements throughout the extrication (Box 1).

Data were captured and analysed using the Biomechanics of Bodies (BoB Biomechanics Ltd, Bromsgrove, UK) software interface before being exported to Excel (Microsoft v. 16.9) and SPSS (IBM v. 25, Armonk NY) for further analysis and reporting [278]. Total excursion, travel, standard deviation and confidence intervals are reported.

We have previously reported data collected using similar techniques which describes maximal movements at the cervical and lumbar spine for self-extrication with and without a collar [281]. A reanalysis of this previously collected data was performed to allow the calculation and reporting of ‘travel’ [281]. Combining the analysis of data collected for both studies allowed for comparative analysis between ‘travel’ for extrication with and without a collar and ‘travel’ associated with collar application.

The study protocol was reviewed and approved by the University of Coventry Research Ethics Committee (reference number P88416).

Results

Data from total of 60 in-vehicle collar applications across three female and three male volunteers was successfully collected for analysis. A mean (range) age across all of the participants was 0.3 (28–68) years and BMI was 27.7 (21.5–34.6).

The results are summarised in Table 7.1 and 7.2, and Figure 7.3. The mean maximal AP movement associated with collar application was 2.3mm with a total AP travel of 4.9mm.

Table 7.1: Participant demographics, mean AP maximal movement and mean AP travel when applying cervical spine collar

Participant	**Age**	**Sex**	**Height (cm)**	**BMI (kg/m2)**	**AP Movement (maximal) mm***	**AP movement (travel) mm***
1	40	F	167	31.9	3.2	6.7
2	52	F	170	34.6	4.0	9.5
3	57	M	168	31.5	2.2	4.6
4	28	F	167	22.2	2.2	4.5
5	68	M	181	24.4	1.4	2.5
6	57	M	179	21.5	0.7	1.3
Mean	50.3		172	27.7	2.3	4.9

BMI = Body Mass Index, AP = Anterior Posterior Movement

*Mean movement across ten applications per participant

Table 7.2: Mean travel for self-extrication with and without collar application

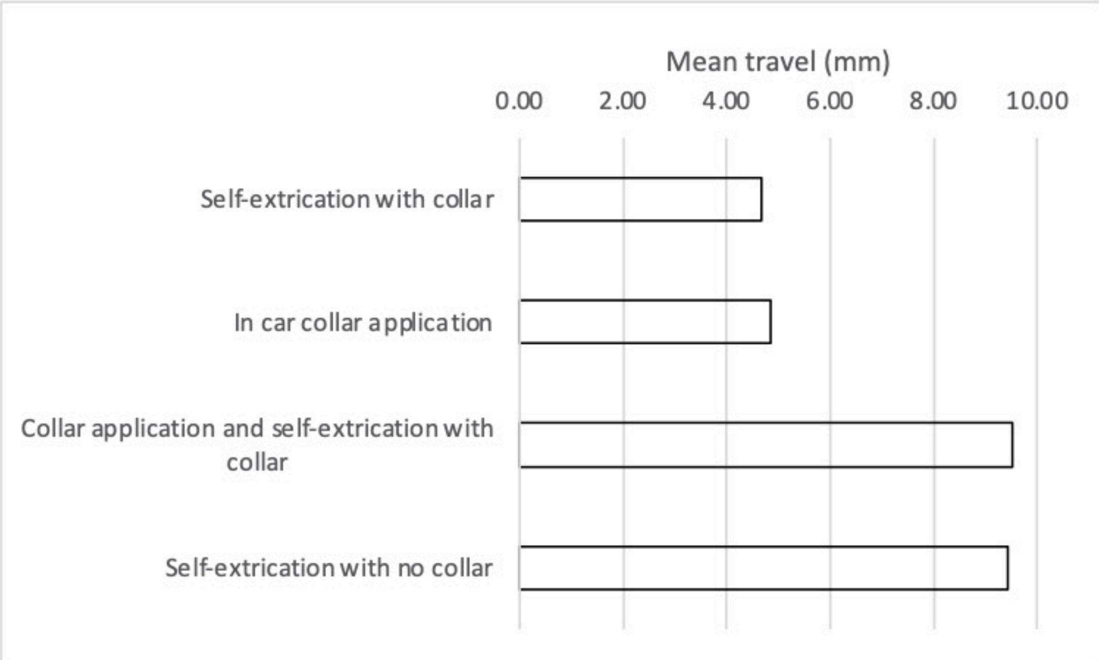
	Mean cervical AP travel [mm]	**Mean cervical LR travel** [mm]	**Mean cervical Roll travel** [degree]	**Mean cervical Pitch travel** [degree]	**Mean cervical Yaw travel** [degree]
Collar Application	4.9	2.2	6.5	13.7	20.1
Self-extrication with collar	4.7	4.8	14.0	13.1	12.2
Self-extrication no collar	9.4	6.8	20.1	26.9	26.7
Difference*	-0.1	-0.1	-0.5	0.1	-5.5

AP = Anterior Posterior Movement, LR = Lateral Movement

*= Self-extrication with no collar – (Collar Application + self-extrication with collar), a negative value indicates larger movement (travel) with collar application and subsequent self-extrication.

Figure 7.3 demonstrates that there is no clinically important difference between cumulative travel across collar application and self-extrication (with collar) when compared to self-extrication without a collar.

FIGURE 7.3: AP TRAVEL AT CERVICAL SPINE (MM)



Discussion

We describe a new metric 'travel' which we demonstrate provides useful context to biomechanical studies considering movement and the potential risk of secondary spinal cord injury. Across healthy volunteer's total 'travel' is approximately equal across cervical spine movements during extrication with and without a collar. The collar may be most effective for minimising large (maximal) movements though still allowing multiple smaller movements – the cumulative effect of which leads to comparable 'travel' [284].

The strength of this new metric is that it allows for the understanding of cumulative movement across an experimental episode (e.g. a single extrication) and as such allows for contextualisation of both total movement and maximal movement when considering potential risk of secondary spinal injury. We suggest that this metric will be particularly useful for comparing extended or complicated biomechanically important procedures (e.g. 'traditional' roof-off extrications). When using IMUs collecting data at a moderate frequency (in this case 40 Hz) no additional data capture is required. The weakness of this metric is that like all biomechanical acquired metrics used in this field of research, it lacks direct clinical correlation – though it remains likely that a smaller ‘travel’ will result in a lesser degree or likelihood of spinal injury. This study relies on a small group of uninjured volunteers who have not experienced a recent MVC, who have had obstructions (coats and hair minimised and with collars applied by two experienced clinicians. These conditions are very different from those experienced in a ‘real life’ MVC and as such affect the external validity of the results when applied to casualties following an MVC.

Although we identified that travel was approximately equal across self-extricating volunteers in this study, we have previously demonstrated that maximal movement is larger when a collar is not used (6.9 mm AP with collar, 28.3mm no collar) [281]. Maximal movement remains an important metric when considering the risk of secondary spinal injury.

Conclusion

‘Travel’ is a useful metric in understanding total movement in biomechanical research. Total travel is similar across self-extricating healthy volunteers with and without a collar.

We suggest ‘travel’ is collected and reported in future biomechanical studies in this and related areas of research. It remains appropriate to apply a cervical collar to self-extricating casualties when the clinical target is that of movement minimisation.

Chapter 8: Assessing spinal movement during four extrication methods: a biomechanical study using healthy volunteers

Declaration from author and co-authors

The following co-authors contributed to the publication: Fenwick R, May B, Stassen W, Smith JE, Bowdler J, Wallis L, Shippen J.

Contributions of the authors were as follows: All authors contributed to the conception and study design. Logistics, data collection and reporting by JS, BM, JB, RF and TN. Initial analysis by TN with clinical interpretation by TN, RF, JES, LW and WS. All authors have contributed to and approved the manuscript.

The extent of contributions from each person are as follows:

- TN: 52.5%
- WS: 7.5%%
- LW: 2.5%
- RF: 12.5%
- JES: 5%
- JS: 7.5%
- BM: 7.5%
- JB: 5%

Given the large number of co-authors, the principal investigator and the supervisor hereby sign for approval on behalf of the group, in accordance with the UCT Doctoral Degrees Board guideline titled, “GUIDELINES FOR THE INCLUSION OF PUBLICATIONS IN A DOCTORAL THESIS.”

25 July 2022

Tim Nutbeam Date

25 July 2022

Willem Stassen Date

Abstract

Background

Motor vehicle collisions are a common cause of death and serious injury. Many casualties will remain in their vehicle following a collision. Trapped patients have more injuries and are more likely to die than their not trapped counterparts. Current extrication methods are time consuming and have a focus on movement minimisation and mitigation. The optimal extrication strategy and the effect this extrication method has on spinal movement is unknown. The aim of this study was to evaluate the movement at the cervical and lumbar spine for four commonly utilised extrication techniques.

Methods

Biomechanical data was collected using inertial Measurement Units on 6 healthy volunteers. The extrication types examined were: roof removal, b-post rip, rapid removal and self-extrication. Measurements were recorded at the cervical and lumbar spine, and in the anteroposterior (AP) and lateral (LAT) planes. Total movement (travel), maximal movement, mean, standard deviation and confidence intervals are reported for each extrication type.

Results

Data from a total of 230 extrications were collected for analysis. The smallest maximal and total movement (travel) were seen when the volunteer self-extricated (AP max = 2.6mm, travel 4.9mm). The largest maximal movement and travel were seen in rapid extrication extricated (AP max = 6.21mm, travel 20.51 mm).

The differences between self-extrication and all other methods were significant ($p<0.001$), small non-significant differences existed between roof removal, b-post rip and rapid removal.

Self-extrication was significantly quicker than the other extrication methods (mean 6.4s).

Conclusions

In healthy volunteers, self-extrication is associated with the smallest spinal movement and the fastest time to complete extrication. Rapid, B-post rip and roof off extrication types are all associated with similar movements and time to extrication in prepared vehicles.

Background

Motor vehicle collisions (MVCs) are a common cause of serious injury and death – accounting for 1.3 million deaths and 50 million serious injuries per annum worldwide [194]. Up to 40% of casualties injured following an MVC will remain trapped – these casualties are more likely to die than their un-trapped counterparts [67,161,196,201,211,285].

Casualties who remain in their vehicle following an MVC will belong in one of four groups: i) The casualty can self-extricate or extricate with minimal assistance (self-extrication), ii) the casualty is unable to self-extricate due to pain, their psychological response to the incident or their injuries but can be assisted from the vehicle (assisted extrication) iii) the casualty is either advised or chooses not to self-extricate due to concern of exacerbating injury (particularly spinal injury) by movement (medically trapped), iv) the casualty is physically trapped in the vehicle (e.g. due to displaced road furniture) or requires disentanglement from the vehicle wreckage by rescue services (disentanglement and rescue) [173]. These groups are not mutually exclusive and a patient may belong in more than one group across their extrication experience.

The role of the rescue services will be different for each casualty group. For example, casualties who can self-extricate will require minimal or no intervention from rescue services but those needing disentanglement and rescue will require the use of cutting and spreading tools [3]. Casualties in the assisted extrication (assisted) and medically trapped (medical) groups can be encouraged to self-extricate, have a rapid extrication (without the use of tools, sometimes referred to as a B plan) or can alternatively have a more traditional extrication, where the vehicle is cut away from around the casualty to improve access and offer an alternative route of egress (sometimes referred to as an A plan extrication) [3].

The approach of the rescue service is based on movement minimisation and mitigation, primarily to avoid exacerbating a primary spinal injury [11].The role of small movements in this is unknown and a challenge to accurately quantify. Large or forceful movements are considered higher risk than smaller movements. Rescue service teaching recommends that casualties in the assisted or medical groups receive a traditional extrication method, as it is understood that these result in less spinal movement than other techniques [11]. Recently these principles have been challenged; with a number of small biomechanical studies demonstrating that self-extrication may cause less movement than more traditional extrication techniques [179,180,182].

Self-extrication or rapid techniques may be superior to traditional A plan techniques in relation to casualty and operational factors. Firstly, the use of extrication tools is not a benign intervention and may cause considerable and costly vehicular damage, will have significant resource implications (both human and equipment), is physically demanding and may also subject casualties and rescuers to a real risk of harm [252]. Secondly, traditional extrication techniques can take a significant amount of time, with a median time of 30 minutes across traditional extrication types [19]. Whilst a patient remains entrapped the ability of clinicians to provide meaningful patient assessment and intervention is limited [20]. The extended time frame associated with traditional extrication and the delays this causes in accessing care may be factors that contribute to the excess mortality and morbidity seen in trapped patients [211]

We have previously demonstrated that spinal injuries occur in 0.7% of patients trapped following an MVC [211]. However, before any change in practice can be recommended, a detailed understanding of the movement of the spine associated with each of the commonly used extrication techniques to support a rigorous comparison of such techniques is important. This study will assess the three most commonly performed extrication techniques along with self-extrication and the resulting spinal movement (Box 1) [4].

Methods

This is an experimental crossover biomechanical study which builds on previous exploratory work and compares spinal movement at both the cervical spine and lumbar spine across each of four extrication techniques: i) Roof removal extrication ii) B-post rip extrication iii) Rapid side door extrication, iv) Self-extrication without instructions.

Participants

Six healthy volunteers were recruited to participate in this study. The volunteers had no previous knowledge of extrication, had no back or neck conditions that may be exacerbated by extrication and had a mass of less than 100kg. Participants were briefed on the study, had access to a participant information sheet in advance and completed written informed consent prior to participation.

Data Collection

Each participant's height and weight were recorded prior to being fitted with the Inertial Measurement Unit (IMU) (Xsens Awinda; Xsens Technologies B.V., Enschede, Netherlands). The characteristics of IMU's and their suitability to extrication research are described in our previous work [281]. The IMU sensor was attached to the head using a headband. The thorax was assumed to be rigid and sensors were positioned over the clavicular notch on the sternum, and over each scapula using a tight-fitting elastic vest. A sensor was positioned on the sacrum by attaching the sensor to shorts using hook-and-loop fastening, to prevent upward travel, and securing the sensor against the body with an elastic belt. Orientation data were collected from each sensor via a wi-fi link and sampled at a rate of 40Hz. Collars were used throughout this study as we have previously demonstrated that they reduce movement during extrication [281]. The Laerdal (Laerdal Medical Corp., Stavanger, Norway) Stiff Neck collars were fitted by a member of the study team trained in their use in accordance with manufacturer guidance.

The vehicle type was pre-specified as a 5-door hatchback as this represents the commonest vehicle type on UK roads [277]. Three similar vehicles were used (Box 8.1). The same intact vehicle was used for the self-extrication and rapid side door extrication arms of the study, with separate pre-prepared vehicles being used for the side-rip and roof-removal arms of the study. Each of these vehicles were prepared with all extrication stages involving cutting equipment and removal of vehicle structure being completed before the study began (Box 8.1 and Figure 8.1).

Box 8.1: Extrication procedures assessed and method of assessment

Roof removal

The A, B and C posts and the roof removed facilitating a vertical extrication technique (Figure 8.1).

Study car preparation: the vehicle was stabilised, all posts were cut, the roof was removed and sharp edges were made safe.

Study vehicle: Peugeot 307 5 door, 2004

Technique: The participant was provided with Manual In-Line Neck Stabilisation (MILNS) throughout, the back support of the driver's seat was reclined mechanically and the Long Spinal Board (LSB) inserted to the seat base. The participant was then slid up the board until they were horizontally situated (securely) on the LSB.

B-post rip

The B-post, drivers and drivers side rear door are removed to facilitate patient access and horizontal extrication (Figure 8.1).

Study car preparation: The vehicle was stabilised, B-post was removed completely using two cuts and all sharps were made safe.

Study vehicle: Peugeot 307 5 door, 2006

Technique: The participant was provided with MILNS throughout. The back support of the driver's seat was reclined mechanically. The LSB was inserted at an oblique angle (pointed towards front centre console) and inserted to the seat base. Participant was then slid up the LSB until fully on the board at which point the LSB is rotated 45 degrees and placed horizontally onto the floor, next to the vehicle.

Rapid

The driver's door is opened and the casualty assisted with a lateral extrication technique.

Study car preparation: The driver's door was opened and the maximal opening angle enhanced using firefighter body weight only.

Study vehicle: Seat Ibiza 5 door, 1999

Technique: The driver's door is opened. The participant was provided with MILNS throughout. The LSB was inserted under the right thigh and hip, through an open door on the driver's side. Hereafter, the participant was then lifted up the LSB in a lateral position until the feet are released from under the steering column, allowing rotation onto back and then finally, slid into position further up the LSB (Figure 8.1)

Self-extrication

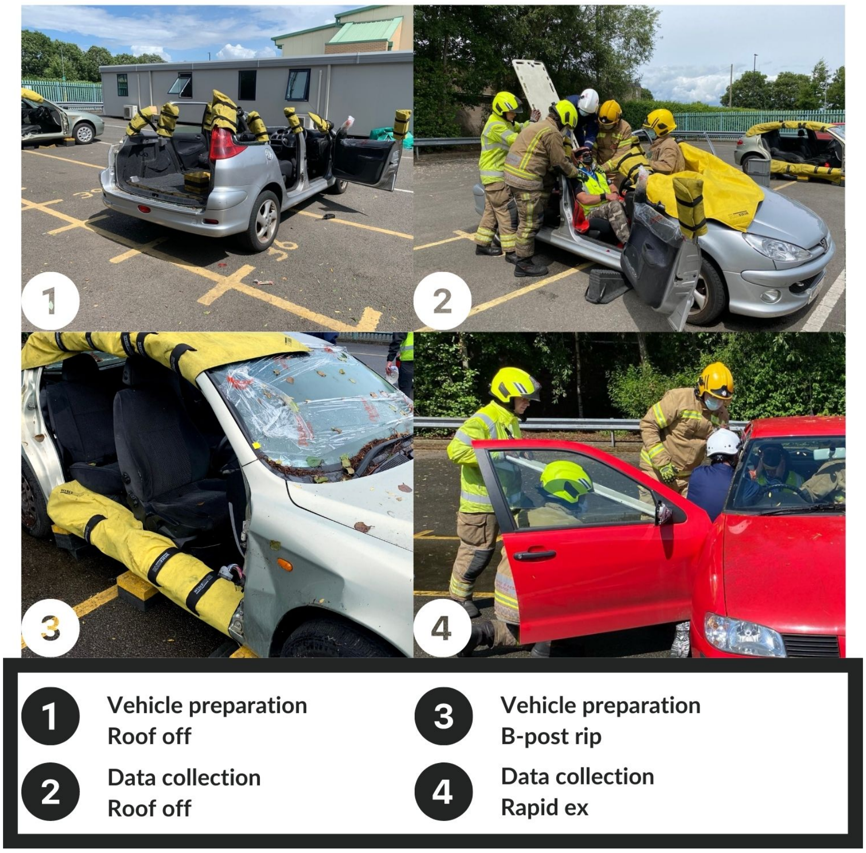
The casualty leaves the vehicle without assistance.

Study car preparation: The drivers door was opened.

Study vehicle: Seat Ibiza 5 door, 1999

Technique: The participant is asked to get out of the vehicle and take one step away. The fire crew offered no instructions on how the participant should exit the vehicle.

FIGURE 8.1 EXTRICATION TECHNIQUE



Sample size

Previous work has identified self-extrication with collar and no instructions to be associated with the least spinal movement during self-extrication; we used the means and standard deviations to power this study [281]. Acknowledging its limitations, we used a minimally clinically important difference (MCID) derived from cadaveric work (2.7mm) [276]. The power calculation was based on finding an anterior-posterior translational movement of 2.7mm with a significance level of 1% and a power of 80%, giving a sample size per group of 57. At each stage, each extrication type was repeated a maximum of ten times with each of the 6 volunteers.

Analysis

The IMU directly measures the segmental orientations from which relative motions can be calculated and reported, by assuming the relative rotations of adjacent vertebrae across the lumbar and cervical region are constant. Maximum excursions (movement from a hypothetical midline) were calculated for anterior/posterior (AP) and lateral (Lat) movement of the cervical and lumbar spine, respectively. In addition to reporting maximum excursions (the single largest movement) we report “travel” - the cumulative total of all movements throughout the extrication.

The time taken for extrication is also considered as a patient-orientated metric. Time for completion of each experiment was therefore also recorded, with the timer starting when the crew declared ready to begin and finishing when the patient was fully extricated and stationary.

Data were captured and analysed using the Biomechanics of Bodies (BoB Biomechanics Ltd,, Bromsgrove, UK) software interface before being exported to Excel (Microsoft v. 16.9) and SPSS (IBM v. 25, Armonk NY) for further analysis and reporting. Total excursions, standard deviation and confidence intervals are reported for each extrication type. P values were calculated using a two tailed t-test comparing each extrication method with the current standard (roof removal) extrication type.

The study protocol was reviewed and approved by the University of Coventry Research Ethics Committee (reference number P88416) and the University of Cape Town, Human Research Ethics Committee (reference number 530/2021).

Results

Data from a total of 230 extrications were successfully collected for analysis (95.8% data capture success rate). Three of the six participants were female, with a mean age across all of the participants of 52 years (range 28-68) and BMI of 27.7 (range 21.5-34.6).

Table 8.1: Participant demographics, extrications and mean AP movement

							Mean AP cervical movement (mm)			
Participant	Sex	Age (years)	Weight (kg)	Height (cm)	BMI (kg/m2)	Extrications for analysis	Roof off	B post rip	Rapid	Self
1	F	40	89	167	31.9	39	4.2	7.0	11.0	2.2
2	F	52	100	170	34.6	38	7.6	7.8	6.5	6.9
3	M	57	89	168	31.5	39	6.6	4.8	7.8	3.0
4	F	28	62	167	22.2	36	7.4	3.9	6.7	0.9
5	M	68	80	181	24.4	38	2.5	5.1	2.3	1.2
6	M	57	69	179	21.5	40	3.0	6.4	3.1	1.6
		50.3	81.5	172.0	27.7	230	5.2	5.8	6.2	2.6

AP = Anterior posterior

Table 8.2: Maximal movement and travel

	Maximal movement during extrication							Travel (total movement) during extrication						
	Roof off	B post	p value	Rapid	p value	Self	p value	Roof off	B post	p value	Rapid	p value	Self	p value
Lumbar AP[mm]	9.65	10.73	0.45	12.47	0.09	4.47	< 0.001	26.56	30.25	0.28	36.07	0.02	8.49	< 0.001
Lumbar Lat [mm]	8.63	10.79	0.27	11.62	0.13	5.67	0.03	21.80	30.70	0.06	37.67	0.008	10.69	< 0.001
Cervical A/P [mm]	5.23	5.86	< 0.001	6.21	< 0.001	2.61	< 0.001	16.69	17.72	0.65	20.51	0.13	4.97	< 0.001
Cervical Lat [mm]	5.11	6.88	0.05	5.60	0.59	2.38	< 0.001	14.56	19.02	0.09	17.68	0.28	4.46	< 0.001
Lumbar roll [^{O}]	18.83	23.47	0.31	25.46	0.14	11.25	0.01	47.59	66.83	0.10	82.49	0.02	21.09	< 0.001
Lumbar pitch [^{O}]	22.91	22.55	0.94	22.33	0.89	8.20	< 0.001	61.63	65.59	0.74	75.97	0.38	15.63	< 0.001
Lumbar yaw [^{O}]	29.80	42.59	0.14	31.65	0.78	11.23	< 0.001	74.73	109.69	0.12	101.09	0.27	21.13	< 0.001
Cervical roll [^{O}]	15.55	20.54	0.08	16.62	0.68	7.07	< 0.001	44.52	55.79	0.16	53.92	0.28	13.31	< 0.001
Cervical pitch [^{O}]	14.90	16.29	0.48	17.55	0.21	7.34	< 0.001	47.32	48.67	0.82	56.51	0.15	13.99	< 0.001
Cervical yaw [^{O}]	20.45	26.60	.098	22.98	0.53	6.10	< 0.001	52.46	69.31	0.07	64.41	0.25	12.14	< 0.001

AP = Anterior posterior

The results are summarised in Tables 8.1-2 and Figures 8.2-6. The mean movements across the four extrication types were 4.4mm (Cervical AP), 4.2mm (Cervical Lat), 7.9mm (Lumbar AP) and 7.8mm (Lumbar Lat). Mean cervical roll was 16.6°, cervical pitch 12.4° and cervical yaw 17.1°. Mean lumbar roll was 16.6°, lumbar pitch 16.0° and lumbar yaw 25.4°.

Figure 8.2: Mean excursion and confidence intervals for anterior-posterior movement at the cervical spine

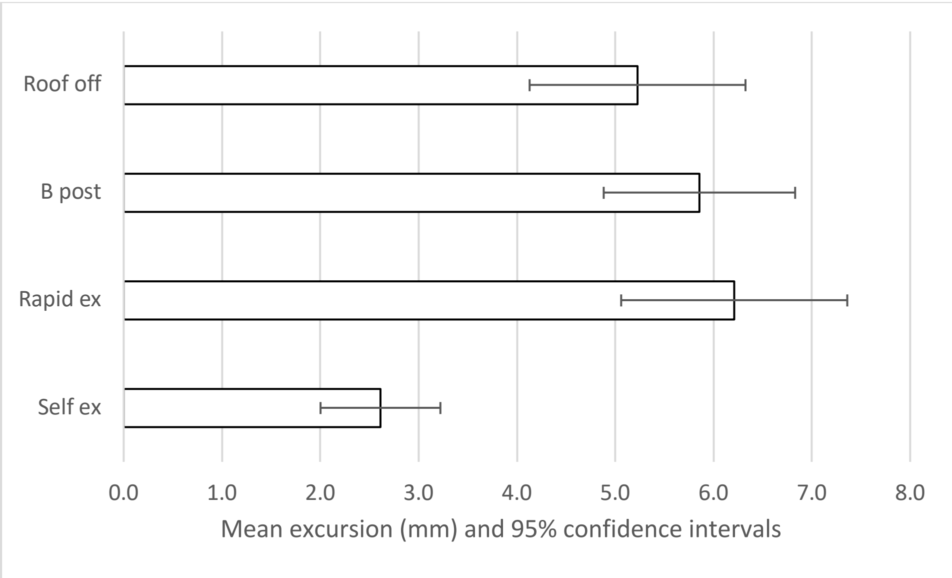


Figure 8.3: Mean excursion and confidence intervals for lateral movement at the cervical spine

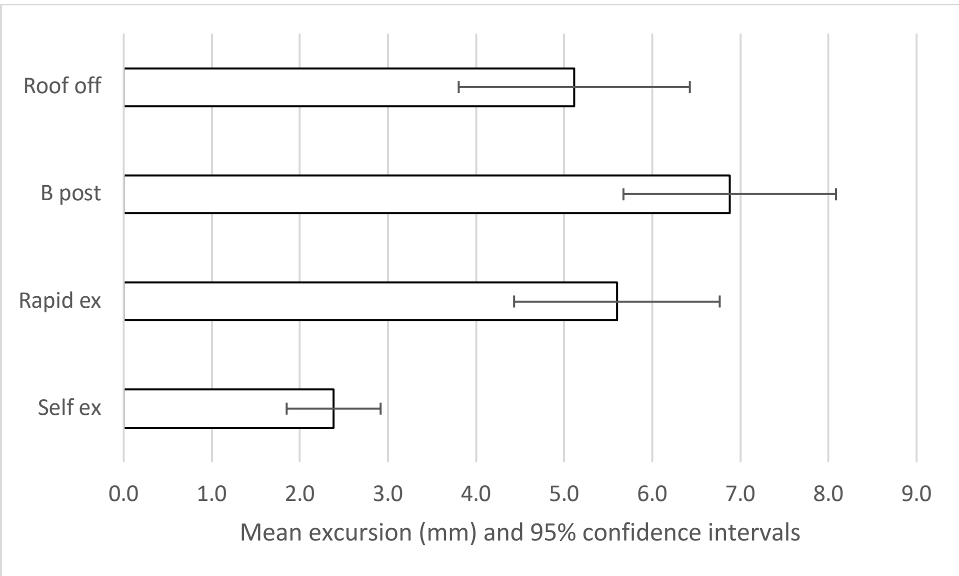


Figure 8.4: Mean excursion and confidence intervals for anterior-posterior movement at the lumbar spine

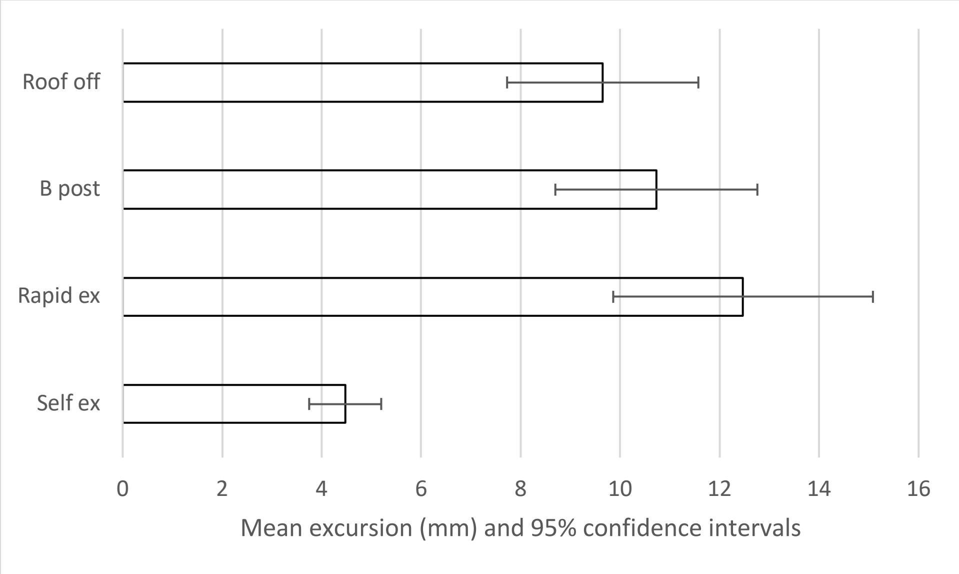


Figure 8.5: Mean excursion and confidence intervals for lateral movement at the lumbar spine

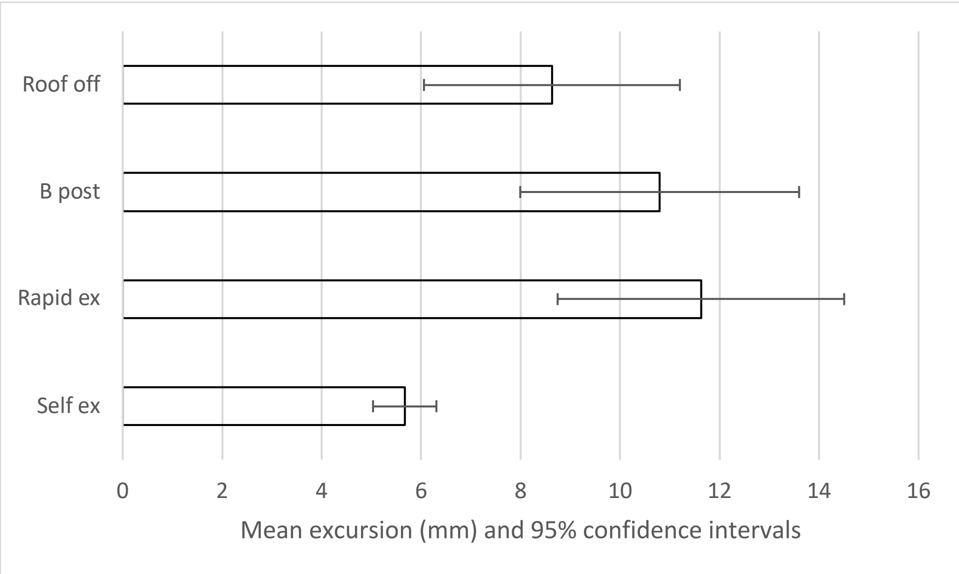
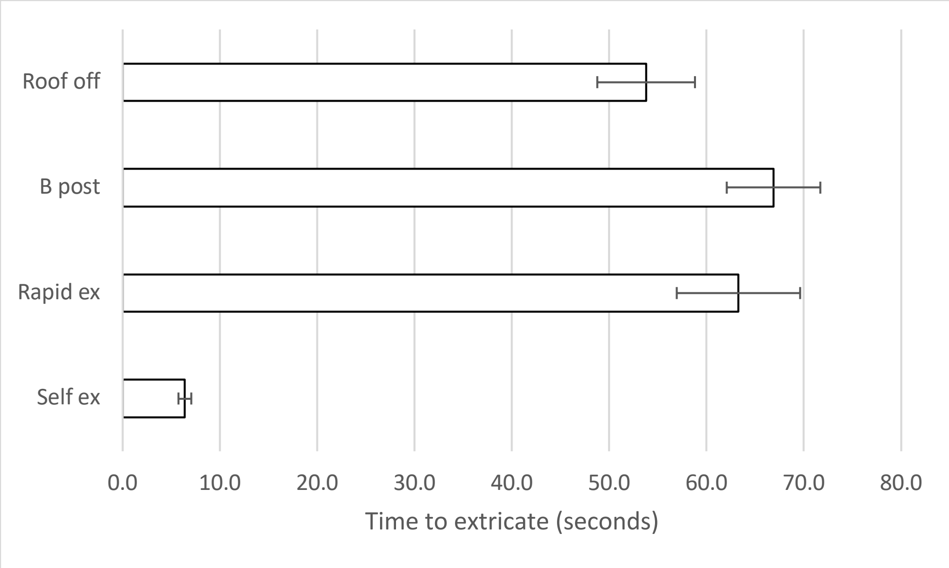


FIGURE 8.6: TIME TAKEN AND CONFIDENCE INTERVALS (S)*



*Time excludes space creation phase (car preparation for extrication)

For the cervical spine, the smallest overall movements were recorded during self-extrication (2.6mm AP and 2.4mm LAT). These were also the conditions producing the smallest movements at the lumbar spine (4.5mm AP and 5.7 mm LAT).

The largest overall mean movements were seen in the cervical spine AP with the rapid side door extrication (6.2mm). For cervical spine lateral movements, the side-rip resulted in the greatest movement (6.9mm). For the lumbar spine, the greatest movement was recorded with the rapid side door extrication (12.5mm AP and 11.6mm LAT).

Self-extrication was significantly quicker than the other extrication methods (mean 6.4s, Figure 8.6). B-post rip extrication (66.9s) was slower than roof-off (53.8s) and self-extrication.

Discussion

This is the first study to define spinal movements associated with each of the commonly used extrication techniques and to perform a powered comparative analysis. This study demonstrates that in healthy volunteers self-extrication results in significantly less movement at the cervical and lumbar spine than other extrication methods.

Results in relation to other studies: Biomechanical studies of extrication are widely heterogenous in design. Similar to the studies of Gabrieli and Dixon we find that self-extrication results in the smallest range of motion at the cervical spine – we offer additional data across a range of volunteers and movements [179,182]. Dixon's team also considered rapid extrication through the driver's door and found as we did that this was associated with the largest movements of the techniques that they considered [182]. Ours is the first study to report movements with the 'roof off' technique or the B post rip which are commonly performed in the UK and in international practice [4].

Clinical and operational interpretation: Rescue service personnel are taught that unstable spinal injury should be assumed following an MVC and that traditional extrication techniques deliver minimal spinal movement, which are preferentially utilised because of this assumed benefit. As a result of this teaching, formal extrications are commonly performed for patients who could self-extricate [173].

This study demonstrates that self-extrication is associated with least spinal movement and the quickest time to extrication. Rapid, B-post rip and roof off extrication types are all associated with similar movements and time to extrication in preprepared vehicles

Trapped patients are more likely to die than patients who are not trapped [211]. Trapped patients may have serious and time dependent injuries and therefore will benefit from an extrication technique which results in the minimum time spent in the vehicle [211]. Current operational practice favours techniques that are time consuming and do not result in the smallest possible patient movement - they do not achieve their intended objectives and as a result their use should be urgently reconsidered. In patients who can self-extricate, this should be the preferred method of extrication as it is associated with the smallest amount (maximal and total) of movement and least time. Self-extrication has many other secondary benefits including potential risk to patient and rescuer, human and equipment resource utilisation and minimises additional damage to the vehicles involved. An alternative extrication approach will be required for the very small minority of patients who are entangled in the vehicle or cannot self-extricate [173,211]. Such patients are likely to be significantly injured and have time critical needs: for these patients, following disentanglement, the quickest deliverable extrication method should be chosen; the correct choice of technique in this context will depend on the actions required to disentangle the patient.

Strengths and weaknesses: Strengths of this study include efforts to maximise internal and external validity by recruiting male and female volunteers inexperienced in extrication with a range of weights, heights and ages. The study methods supported data collection from real vehicles, prepared as they would be for a ‘real life’ extrication, using active-duty rescue personnel. We successfully collected data from a large number of extrications to meet the pre-specified power calculation, supporting confidence in the reported results.

Our volunteers were uninjured, fully conscious and had not recently experienced an MVC and did not have ‘true’ entrapment requiring disentanglement, as such the applicability of these results to the injured post collision population needs careful consideration. The volunteers were subjected to multiple extrications across a short time; we could find no evidence of ‘learning’ in the movements recorded but this could have influenced our results unknowingly. The rescue personnel also performed multiple extrications over the day – a far greater exposure than in operational practice. We did see faster extrications as the teams became increasingly familiar both with the techniques and working together as a team. Fatigue of the extrication team may also have influenced our results.

Further work

Additional biomechanical work could evaluate alternative extrication techniques (such as Scandinavian chain cabling [175]. Biomechanical models using healthy volunteers are unlikely to offer definitive answers; evolving technology has supported the collection of data in ‘near operational’ scenarios but is unlikely to be successful in collecting data on actual injured patients. As the paradigms of spinal immobilisation are challenged and additional data is made available as to the rarity of isolated unstable spinal injury in the context of other time critical injuries [211], those with responsibility for guidance and expertise in the area of extrication, trauma care and spinal injuries must work with patients and their representatives to evolve new approaches to extrication which improve the care of and outcome for our patients.

Conclusions

In healthy volunteers, self-extrication is associated with the smallest patient spinal movement and the fastest time to complete extrication. Rapid, B-post rip and roof off extrication types are all associated with similar movements and time to extrication in preprepared vehicles. In patients who can self-extricate, this should be the preferred extrication method. In patients who can't self-extricate, following disentanglement the most rapid method of extrication should be delivered.

Chapter 9: Comparison of 'chain cabling' and 'roof off' extrication types, a biomechanical study in healthy volunteers

Declaration from author and co-authors

The following co-authors contributed to the publication: Fenwick R, May B, Stassen W, Smith JE, Bowdler J, Wallis L, Shippen J.

Contributions of the authors were as follows: All authors contributed to the conception and study design. Logistics, data collection and reporting by JS, BM, JB, RF & TN. Initial analysis by TN with clinical interpretation by TN, RF, JS, and WS. All authors have contributed to and approved the manuscript.

The extent of contributions from each person are as follows:

- TN: 52.5%
- WS: 7.5%
- LW: 2.5%
- RF: 12.5%
- JES: 5%
- JS: 7.5%
- BM: 7.5%
- JB: 5%

Given the large number of co-authors, the principal investigator and the supervisor hereby sign for approval on behalf of the group, in accordance with the UCT Doctoral Degrees Board guideline titled, "GUIDELINES FOR THE INCLUSION OF PUBLICATIONS IN A DOCTORAL THESIS."

	25 July 2022
Tim Nutbeam	Date
	25 July 2022
Willem Stassen	Date

Abstract

Introduction

Following an MVC some patients will remain trapped. Traditional extrication methods are time consuming and focus on movement minimisation and mitigation. 'Chain cabling' is an alternative method of extrication used in some Scandinavian countries. The optimal extrication strategy and the effect of extrication methods on spinal movement is unknown. This study compares 'chain cabling' to the established roof removal method of extrication on spinal movement.

Methods

Biomechanical data were collected using Inertial Measurement Units on a single healthy volunteer during multiple experiments. The extrication types examined were chain cabling and roof removal. Measurements were recorded at the cervical and lumbar spine, and in the anteroposterior (AP) and lateral (LR) planes. Total movement (travel), maximal movement, mean, standard deviation and confidence intervals are reported.

Results

Eight experiments were performed using each technique. The smallest mean overall movements were recorded during roof-off extrication (cervical spine 0.6mm for AP and LR, lumbar spine 3.9mm AP and 0.3 mm LR).

The largest overall mean movements were seen with chain cabling extrication (cervical spine AP 5.3mm. LR 6.1mm and lumbar spine 6.8mm AP and 6.3mm LR).

Conclusion

In this study of a healthy volunteer, roof-off extrication was associated with less movement than chain cabling. The movement associated with chain cabling extrication was similar to that previously collected for other extrication types.

Highlights

- Patients who are trapped following an MVC are more likely to die.
- Chain cabling extrication was associated with more movement in all planes at the cervical and lumbar spine when compared to ‘roof off’ extrication in this biomechanical analysis
- In comparison to historically collected data with identical methods, chain cabling performed similarly to other extrication types

Introduction

Motor vehicle collisions (MVCs) are a common cause of injury and death [194]. Following an MVC casualties that remain trapped in their vehicles are at risk of more severe injuries and are more likely to die [211].

Extrication is the process of removing casualties with known or potential injuries from their vehicles [211]. Rescue services have developed a wide range of techniques to enable access to casualties and extricate them from their vehicles [3]. Many 'traditional' extrication techniques have developed with a primary focus on movement minimisation because of concerns related to the potential for excessive movement either causing or contributing to secondary spinal injury [11]. Movement minimisation during extrication comes at the expense of time, with extrications on average taking in excess of 30 minutes [19]. Trapped casualties can have significant injuries, some of which may be time dependent [211]. As such some casualties will benefit from rapid extrication and minimal entrapment time [211].

An alternative to traditional extrication techniques with a focus on rapidity of casualty access and extrication termed 'chain cabling' or the 'Norwegian chain method' is used in some areas of Europe [175]. Chain cabling involves attaching anchored chains or strops to the front and rear posts of the damaged vehicle and using a winch to apply traction to the vehicle, therefore reversing the forces and vehicle distortion associated with a frontal collision (see Box 9.1). A previous study of this method has demonstrated both its acceptance by rescue personnel and its rapidity of successful extrication in a rescue competition environment, with a median extrication time of 12.5 minutes compared to 30 minutes for UK rescue services utilising traditional techniques outside of the competition environment [19,175].

Potential barriers to adoption of 'chain cabling' include suitability of road environment, availability of equipment and training, and concerns related to potential harmful movement of the casualty during this technique [3]. Previous biomechanical analyses of traditional extrication techniques have identified that the spinal movements associated with each technique were not as expected and have demonstrated the utility of understanding movements associated with commonly used extrication methods [247].

The aim of this study was to quantify the spinal movements associated with 'chain cabling' extrication using the commonly performed 'roof off' type extrication as a comparator.

Methods

This was an experimental crossover biomechanical study which builds on previous exploratory work and compares spinal movement at both the cervical spine and lumbar spine between 'chain cabling' and 'roof off' extrication types. Roof off was chosen as it is the most frequently delivered technique by rescue services [4].

Participant: A single healthy volunteer was recruited to participate in this study and completed all experiments. The participant was briefed on the study, had access to a participant information sheet in advance and completed written informed consent prior to participation.

Data Collection: The participant's height and weight were recorded prior to being fitted with the Inertial Measurement Unit (IMU) (Xsens Awinda; Xsens Technologies B.V., Enschede, Netherlands). The characteristics of IMU's and their suitability to extrication research are described elsewhere [281]. The IMU sensor was attached to the head using a headband. The thorax was assumed to be rigid and sensors were positioned over the clavicular notch on the sternum, and over each scapula using a tight-fitting elastic vest. A sensor was positioned on the sacrum by attaching the sensor to shorts using hook-and-loop fastening, to prevent upward travel, and securing the sensor against the body with an elastic belt. The participant was equipped with fire-retardant personal protective equipment (PPE) including a helmet (with visor) to provide head and face protection. Orientation data were collected from each sensor via a wi-fi link and sampled at a rate of 40Hz. A rigid cervical collar was worn throughout this study as we have previously demonstrated that they reduce movement during extrication [281]. A Laerdal (Laerdal Medical Corp., Stavanger, Norway) Stiff Neck collar was fitted by a member of the study team trained in its use and in accordance with manufacturer guidance.

Vehicle preparation: The vehicle type was pre-specified as a 5-door hatchback as this represents the commonest vehicle type on UK roads [277]. Details of the 'Chain Cabling' car preparation and process can be found in Box 9.1. For the 'Roof removal' data collection, the car was pre-prepared with the A, B and C posts and the roof removed facilitating a vertical extrication technique. All sharp edges were made safe.

The participant was provided with Manual In-Line Neck Stabilisation (MILNS) throughout, the back support of the driver's seat was reclined mechanically and the Long Spinal Board (LSB) inserted to the seat base. The participant was then slid up the board until they were horizontally situated (securely) on the LSB.

Sample size: Previous work has provided mean and standard deviations for a range of volunteers undergoing 'roof off' extrication. Acknowledging its limitations, we used a minimally clinically important difference (MCID) derived from cadaveric work (2.7mm) [276]. The power calculation was based on finding an anterior-posterior translational movement of 2.7mm with a significance level of 5% and a power of 80%, giving a sample size per group of 8 extrications.

Analysis: The IMU directly measures the segmental orientations from which relative motions can be calculated and reported, by assuming the relative rotations of adjacent vertebrae across the lumbar and cervical region are constant. Maximum excursions (movement from a hypothetical midline) were calculated for anterior/posterior (AP) and lateral (LR) movement of the cervical and lumbar spine, respectively. In addition to reporting maximum excursions (the single largest movement) we report "travel" – the cumulative total of all movements throughout the extrication [286].

Data were captured and analysed using the Biomechanics of Bodies (BoB Biomechanics Ltd, Bromsgrove, UK) software interface before being exported to Excel (Microsoft v. 16.9) and SPSS (IBM v. 25, Armonk NY) for further analysis and reporting. Maximal excursions, travel (total movement), standard deviation and confidence intervals are reported for each extrication type.

The study protocol was reviewed and approved by the University of Coventry Research Ethics Committee (reference number P88416) and the University of Cape Town, Human Research Ethics Committee (reference number 531/2021).

Box 9.1: Chain Cabling and Vehicle Preparation

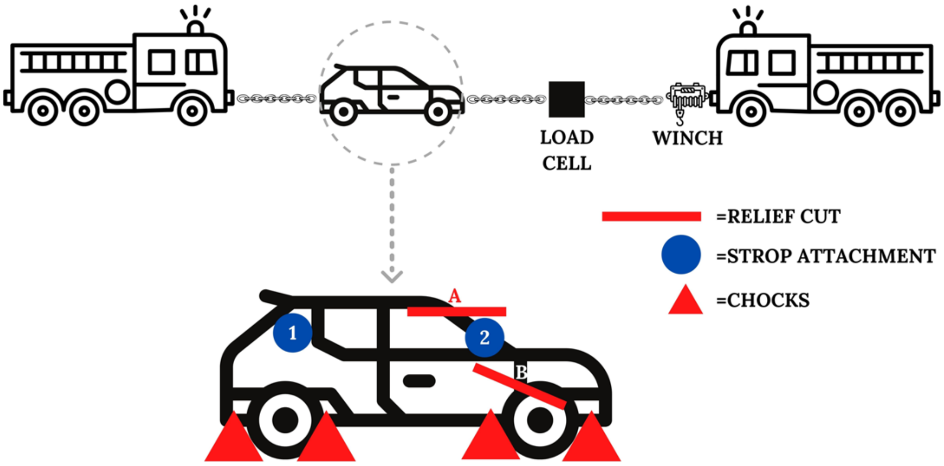


Figure 9.1: Chain-cabling equipment and vehicle position and orientation

Technique: The technique involves the applying of tension to the vehicle containing a trapped casualty using chains or strops. For this study, a fire appliance was positioned at each end of the vehicle with both appliances being secured by their hand brake and chocks. The appliances acted as anchors for an electric winch (Rotzler TR080/6 8 tonne constant pull) or 3.2 ton manually operated (Tirfor) winch secured between the front appliance and the strops. The strops were secured to the central reinforced area of the 'A' post of the car (2) containing the casualty and then to the winch cable and front anchor. The rear strop was secure around the 'C' post of the vehicle and then to the rear anchor (Figure 9.1).

Vehicle preparation: Eight similar vehicles were used with a new vehicle being utilised for each data collection. Relief cuts are made with a cutting tool at 45 degree angle to bottom of the 'A' post and into the sill on each side of the vehicle (Figure 9.2).

FIGURE 9.2: PHOTOGRAPH DEMONSTRATING RELIEF CUT POSITION

The central transmission tunnel check straps where not unbolted or cut. Further cuts are made through the top of the ‘A’ posts and the top of the windscreen of the car was cut between the top of the ‘A’ posts with a cutting tool (A). The vehicle was stabilised by supporting the undercarriage with chocks and vehicle handbrake was engaged.

Experiment: Traction was placed across the front strops using the winch. A load cell was used which allowed remote monitoring of the forces being applied and resistance from the vehicle construction so the traction could be halted if pre-specified safety values were exceeded. Traction was applied until the front bumper of the car made contact with the simulated road or if sufficient access was achieved to establish a viable extrication pathway as shown in the photograph below (Figure 9.3).

FIGURE 9.3: POSITION OF VEHICLE AT COMPLETION OF TRACTION PHASE

Results

Data from a total of 16 extrications were successfully collected for analysis; 8 repetitions of chain cabling and 8 using the roof off extrication technique. The results are summarised in Tables 9.1 and 9.2, and Figures 9.4 - 5.

For the cervical spine, the smallest mean overall movements were recorded during roof off extrication (0.6mm for AP and LR). Roof off extrication also produced the smallest mean movements at the lumbar spine (3.9mm AP and 0.3 mm LR).

The largest overall mean movements were seen in the cervical spine movements with the chain cabling extrication (AP 5.3mm and LR 6.1mm). For the lumbar spine, the greatest mean movement was recorded with the chain cabling extrication type (6.8mm AP and 6.3mm LR).

Table 9.1: Chain Cabling Maximal Movements

Trial	Cervical AP (mm)	Cervical LR (mm)	Lumbar AP (mm)	Lumbar LR (mm)	Cervical Roll (°)	Cervical Pitch (°)	Cervical Yaw (°)	Lumbar Roll (°)	Lumbar Pitch (°)	Lumbar Yaw (°)
1	12.4	7.1	10.5	5.0	29.4	20.4	71.7	25.9	16.8	38.2
2	5.5	4.0	4.7	1.1	17.6	12.1	17.2	5.6	8.6	8.9
3	2.5	4.0	11.0	18.1	13.3	7.4	28.6	77.0	59.4	132.2
4	5.3	10.8	12.2	8.4	34.5	12.6	28.1	41.5	39.2	61.5
5	1.2	2.8	2.2	2.0	7.7	4.8	10.6	10.7	2.2	14.8
6	1.9	2.2	1.7	1.1	8.4	4.2	11.8	5.4	3.2	8.7
7	3.0	1.7	3.0	3.0	5.8	7.3	17.4	12.4	9.3	20.9
8	10.3	16.3	8.8	11.4	26.1	38.4	103.7	36.1	41.7	63.5
MEAN	5.3	6.1	6.8	6.3	17.9	13.4	36.1	26.8	22.6	43.6
STDEV	4.1	5.1	4.3	6.0	10.9	11.4	33.6	24.5	21.4	42.0

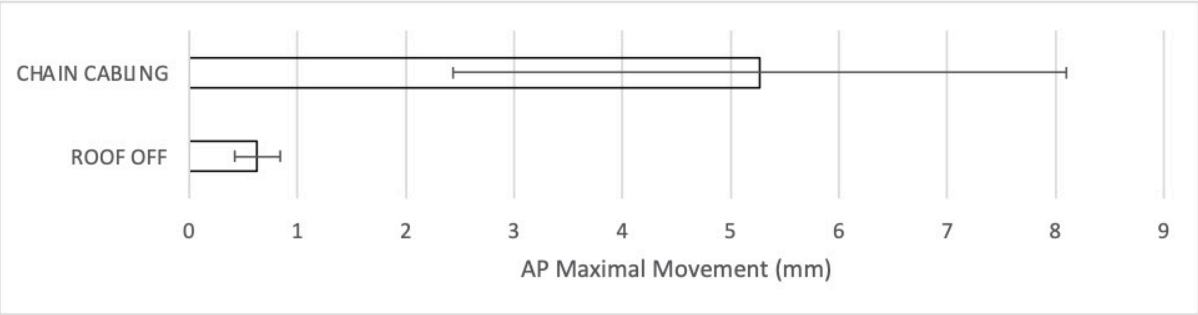
AP= Anterior posterior, LR = Lateral. Participant height = 186 cm, Mass = 79kg, BMI = 22.8 kg/m^2

Table 9.2: Roof Off Maximal Movements

Trial	Cervical AP [mm]	Cervical LR [mm]	Lumbar AP [mm]	Lumbar LR [mm]	Cervical Roll [^{O}]	Cervical Pitch [degree]	Cervical Yaw [^{O}]	Lumbar Roll [^{O}]	Lumbar Pitch [^{O}]	Lumbar Yaw [^{O}]
1	1.2	1.1	4.6	0.4	3.3	3.3	1.7	2.2	8.7	2.4
2	0.5	0.8	4.3	0.2	2.3	1.3	1.4	1.1	8.2	2.2
3	1.0	0.6	1.8	0.4	1.7	2.8	2.2	1.8	3.4	3.1
4	0.5	0.4	1.5	0.3	1.2	1.3	1.0	1.2	2.9	1.4
5	0.4	0.4	2.7	0.2	1.1	1.2	1.3	1.3	5.1	2.1
6	0.4	0.6	4.4	0.2	1.6	1.3	1.1	1.1	8.4	1.5
7	0.5	0.3	4.6	0.3	1.0	1.4	1.1	1.6	8.8	1.6
8	0.5	0.7	7.6	0.4	1.9	1.4	1.5	3.2	14.6	3.1
MEAN	0.6	0.6	3.9	0.3	1.8	1.8	1.4	1.7	7.5	2.2
STDEV	0.3	0.3	2.0	0.1	0.8	0.8	0.4	0.7	3.8	0.7

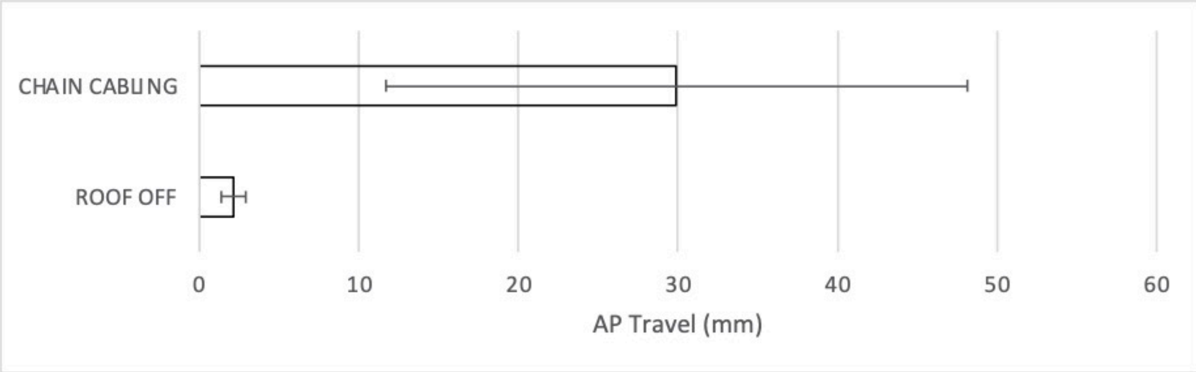
AP= Anterior posterior, LR = Lateral.

Figure 9.4: Cervical AP Maximal Movement*



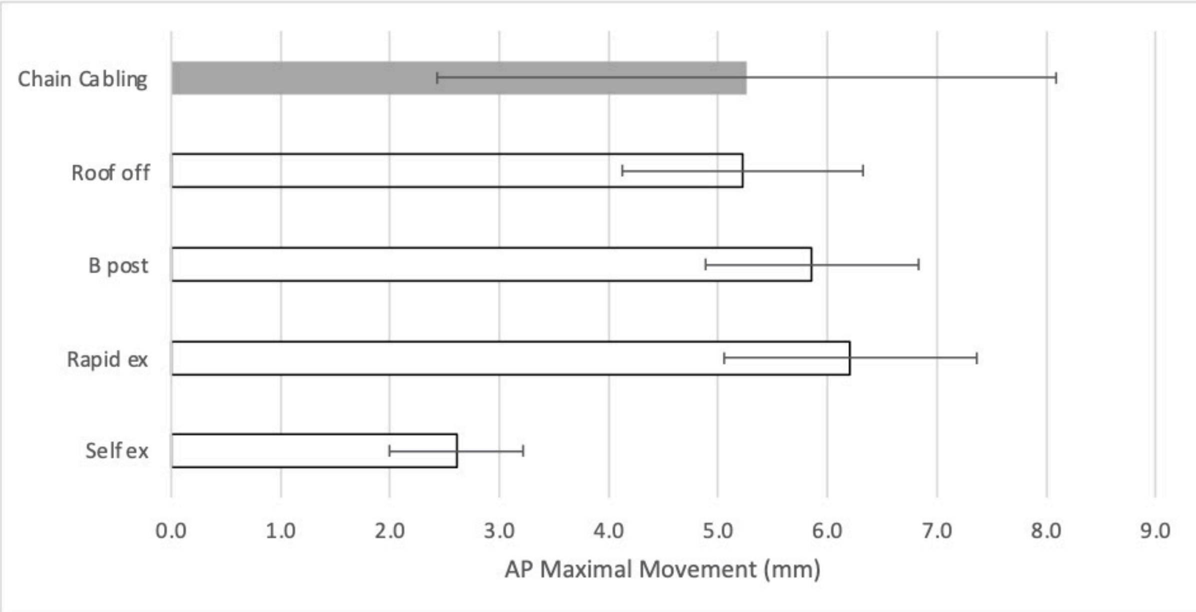
*Error bars indicate 95% Confidence Intervals

Figure 9.5: Cervical AP Travel*



*Error bars indicate 95% Confidence Intervals

Figure 9.6: Chain cabling extrication compared to other extrication types*



Error bars indicate 95% Confidence Intervals

Discussion

This is the first study to report movements at the cervical and lumbar spine during chain cabling extrication. This demonstrates that for a healthy volunteer, roof off extrication was associated with less movement at the cervical and lumbar spine than chain cabling extrication.

Clinical and operational interpretation: There is a conflict in extrication planning and delivery between speed of patient access and extrication, and the casualty movement associated with this. Concerns in relation to excessive patient movement have their origins in the controversial belief that such small movements may contribute to secondary spinal injury. We have previously demonstrated that unstable spinal injuries and cord injuries in isolation are very rare in injured entrapped patients, whereas other time critical injuries (such as head and chest injuries) are much more common [211]. Rescue and clinical services have moved towards increased utilisation of rapid extrication methods over recent years [4]. Considering the similarity in maximal movements across all extrication types (with the exception of self-extrication) it remains appropriate to recommend the quickest deliverable extrication method considering the clinical details and operational environment (Figure 9.6).

Chain cabling extrication can be considered to consist of two phases: the traction phase where tension is applied to the vehicle (where very little casualty movement occurs) and the casualty removal phase (where the maximal movement occurs). From a bio-mechanical perspective the casualty movements required to facilitate the casualty removal phase of chain cabling are very similar to the ‘rapid ex’ type method. Consideration should be given to the use of chain cabling as a route of gaining patient access and where appropriate considering an alternative method (e.g., self-extrication) for the casualty removal phase.

Chain cabling is currently delivered routinely by some Scandinavian rescue services and in some areas of Europe. To facilitate chain cabling in other regions would require a significant investment in training, equipment, logistics and process development. When considering chain cabling in comparison to other more routinely delivered methods of extrication it is hard to justify this investment based upon extrication time or minimisation of patient movement where other quicker, established methods with similar movement profiles exist. However, where chain cabling is unique when compared to the other extrication methods is that it has a role in patient disentanglement. This disentanglement occurs when the process of chain cabling physically changes the structure of the vehicle, releasing lower limb entrapment; it may have either a dual role or an advantage over other extrication methods in this respect.

Limitations

Strengths and weaknesses: A strength of this study is the collection of biomechanical data during dynamic extrication and car movement. We successfully collected data from an appropriate number of extrications to meet the pre-specified power calculation, which allows some confidence in the reported results.

We utilised real vehicles and active-duty rescue personnel to support its internal and external validity. This study was limited by the use of a single uninjured participant and therefore the movements recorded may not be representative of the wider population. Interestingly the movements recorded from our volunteer in roof off extrication type were smaller than those previously reported across a range of healthy volunteers using similar methodology (previously mean 5.2mm AP, 5.11 LR at the cervical spine v's 0.6mm for both from this study) which needs to be considered in the context of the potential external validity of the roof off results [247].

As the paradigm of absolute movement mitigation continues to be challenged and increasing evidence emerges of extrication methods not performing as expected those with responsibility for operational guidance and protocol development in the areas of extrication, trauma care and spinal injury must work with patients and their representatives to evolve new evidence-based, patient-centred approaches to extrication.

Conclusions

In this study of a healthy volunteer, roof-off extrication was associated with less movement than chain cabling. The movement associated with chain cabling extrication was similar to that previously collected for other extrication types.

Section discussion

This section presents four biomechanical studies considering a variety of extraction types. The first paper focuses on self-extrication, where we demonstrate the effectives of collars to reduce movement at the cervical spine in this setting; in the second paper we present a novel metric to describe biomechanical analysis in relation to spinal movement, the third paper considers four different extrication types (self, rapid, b-post rip and roof-off extrication types) and the fourth paper considers chain cabling extrication.

In this analysis we demonstrate that self-extrication is superior to other extrication types when considering minimising of movement at the cervical and lumbar spine. The alternative extrication types considered are similar to each other in movement minimisation with the 95% confidence intervals all overlapping. Collars are effective at reducing movement at the cervical spine in the context of self-extrication.

There are challenges with this analysis which need consideration in understanding the translation of findings to the real-world environment / injured population. The power calculation for all studies relied on a single MRI study which reported a small difference in AP spinal canal space between injured cervical spines with cord injury and injured cervical spines without cord injury [276]. This was the best available metric from which to power the studies reported here and had been previously recommended by researchers in this area of study[182]. The metric is limited as the direct correlation between ‘external’ movement of the spine and a resultant ‘internal’ displacement is unknown. Furthermore, the original study is small and failed to identify a statistical relationship between_canal space and American Spinal Injury Association impairment score. In the absence of an alternative published metric of the ‘acceptable’ maximum threshold (movement or travel) for safe external movement of the spine then it is reasonable to assume that smaller movements are better than larger movements. As the same measuring methods, equipment and study team were used for each of these analyses the internal and inter-study validity of the results is maximised; it is likely that the comparison between the extrication methods is valid.

Translation of these results from uninjured volunteers to patients with primary unstable spinal injury is challenging and difficult to resolve. Evolutions in biomechanical technology may enable collection of data on real patients in operational circumstances. If the technology challenge is overcome, collecting enough data to offer meaningful insight in this area will prove difficult. In the last available year of FRS data in England (April 20 – April 21) there were 2502 extrications recorded in the national dataset [198]. If we assume all these patients are majorly injured (an overestimate) and have a spinal cord injury rate similar to that reported in Chapter 2 (0.7%) then to gather data from 57 patients with cord injury in each of the four extrication types would require 100% data collection over a minimum of 13 years. This trial would be lengthy, costly, logistically challenging, and as such is likely to be unachievable. As discussed in the introduction to this section there are challenges to the various to commonly used ‘models (e.g. animal / cadaveric / healthy volunteer) as alternatives to inform this clinical question; data with improved external validity is unlikely to be forthcoming.

Key messages: Section 3

- Self-extrication is associated with smaller movements at the cervical and lumbar spine than other extrication types.
- Extrication types that are not self-extrication appear to be similar in movement generation at the cervical and lumbar spine.
- There are challenges with the external validity of a model that uses healthy volunteers: this is unlikely to be resolved conclusively by the adoption of an alternative model or data-collection in the real-world.

Section 4:

Patient values and preferences

Section introduction:

Section 4 relates to the "patient values and preferences" section of the EBM framework. This section presents a single paper which focuses on the patient experience of extrication. Patient values and preferences are a core element of Evidence Based Medicine [15]. Patient engagement and dialogue leads to a deeper understanding of a healthcare problem and higher levels of engagement with research outcomes [287,288]. The full benefits (and costs) of patient involvement are unknown and heterogeneously reported; but are considered an essential component of current research practices [289,290].

Patient groups

The purpose of this study was to capture the patient experience of extrication and describe modifiable factors that may lead to an improved patient experience. A review of the literature revealed very few publications relative to this field; with no papers considering the patient experience of entrapment and extrication with a majority of authors focusing on the prevalence and description of symptoms associated with Post Traumatic Stress Disorder (PTSD) [70,291,292].

As discussed in Chapter 1 and 2; current extrication techniques have evolved around the principle of movement minimisation to prevent secondary spinal injury. As such, it was important for the sample of patients interviewed for this paper to include both patient's with and without spinal injury. Initially patients were successfully recruited by an air ambulance service (Devon Air Ambulance Trust, Devon, UK), as may be expected (given the low prevalence) none of the sample had spinal injuries or suspected spinal injuries. In order to ensure that the perspective of the spinal injured patient was included we approached a spinal injuries support charity (ASPIRE, UK) who invited their clients to contribute to this research.

Choice of interviewer

The rate of PTSD following MVC is high [86]. To ensure maximum interview quality with minimum patient distress and appropriate, expert de-escalation if required a trained psychotherapist with extensive experience of qualitative interviewing was recruited to deliver the interviews (JB). It was considered detrimental to the efficacy of the interviews and a source of bias to include the primary researcher (TN) as an interviewer or observer (TN has a role of medical lead for the recruiting air ambulance service).

Timing and location of interviews

Participating patients were considered for recruitment a minimum of six weeks post incident; the six-week window appears to offer a considered balance between retention of memories and recovery from immediate peri-traumatic psychological sequalae [293,294].

The planned interviews were affected by the COVID-19 pandemic and therefore could not be delivered face-to-face as originally planned. This presented an opportunity to enable access to injured and disabled participants via the utilisation of secure online video communications software.

The next chapter which makes up the remainder of this section present an original paper which is reproduced in full but formatted to provide consistency throughout this thesis. This section ends with a discussion of the contributory chapter and relates their findings and outcomes to the thesis as a whole.

Chapter 10: Understanding people's experiences of extrication whilst being trapped in motor vehicles: a qualitative interview study

Declaration from author and co-authors

The following co-authors contributed to the publication: Brandling J, Wallis L, Stassen W.

Contributions of the authors were as follows: TN, WS, JB and LW contributed to the conception and design of the study. JB conducted the interviews. TN, WS, JB contributed to the analysis and interpretation of data and drafted the paper. All authors contributed to revision of the paper and gave final approval of the version to be published.

The extent of contributions from each person are as follows:

- TN: 50%
- JB: 20%
- LW: 20%
- WS: 20%

Given the large number of co-authors, the principal investigator and the supervisor hereby sign for approval on behalf of the group, in accordance with the UCT Doctoral Degrees Board guideline titled, "GUIDELINES FOR THE INCLUSION OF PUBLICATIONS IN A DOCTORAL THESIS."

	25 July 2022
Tim Nutbeam	Date
	25 July 2022
Willem Stassen	Date

Abstract

Objective

To explore patient's experience of entrapment and subsequent extrication following a motor vehicle collision and identify their priorities in optimising this experience

Design

Semi-structured interviews exploring the experience of entrapment and extrication conducted at least six weeks following the event. Thematic analysis of interviews.

Setting

Single air ambulance and spinal cord injury charity in the UK

Participants

10 patients were recruited and consented; 6 air ambulance patients and 2 spinal cord injuries charity patients attended the interview. 2 air ambulance patients declined to participate following consent due to the perceived potential for psychological sequelae.

Results

The main theme across all participants was that of the importance of communication; successful communication resulted in a sense of wellbeing and where communication failures occurred this led to distress. The data generated three key sub-themes; 'on-scene communication', 'physical needs' and 'emotional needs'. Specific practices were identified that were of use to patients during entrapment and extrication.

Conclusions

Extrication experience was improved by positive communication, companionship, explanations and planned post-incident follow-up. Extrication experience was negatively affected by failures in communication, loss of autonomy, unmanaged pain, delayed communication with remote family and onlooker use of social media.

Recommendations which will support a positive patient centred extrication experience are the presence of an "extrication buddy", the use of clear and accessible language, appropriate reassurance in relation to co-occupants, a supportive approach to

communication with family and friends, the minimisation of onlooker photo/videography and the provision of planned (non-clinical) follow up.

Strengths and limitations of this study

This study provides new insights into the experience of patients undergoing extrication: an area of previously very limited understanding

This study is strengthened by conducting and reporting to CORDEQ guidelines

This study is limited it is single centre and only featured English speaking adults from the UK. The transferability in respect to lower-middle-income countries and other patient groups (especially children) may be limited.

Background

Motor vehicle collisions (MVCs) are a major cause of injury and death [194]. Following an MVC some patient's will remain trapped in their vehicle [67]. Entrapment following an MVC is associated with significant injuries and excess deaths [211].

Patients who are trapped following an MVC may require assistance to leave their vehicle. The type and amount of assistance will vary with the individual characteristics of the patient and the incident [3]. The process of removing a patient from a vehicle is known as 'extrication' [252].

Extrication practice has evolved over the last 50 years – from informal, ad-hoc rescue services to todays' situation with a legislated response, bespoke commercial tool manufacturers, industry standards and national operational guidance [3,30,175,252]. The current accepted norms of extrication by rescue services include a primary focus on movement mitigation. This approach has evolved with the intention of minimising secondary spinal injury. To achieve absolute movement mitigation, rescue services will use cutting tools to create new methods of egress (such as removing the roof) and extricate the patient with the assistance of spinal boards and other movement restriction devices. Cutting tools are noisy and potentially dangerous to the patient and the rescuer. These extrication methods can be technically difficult to achieve, require considerable resources and take time to deliver; as such, the patient will be trapped for longer. New evidence that describes the injuries of trapped patients and outlines the excess death associated with entrapment indicates that current extrication approaches may not achieve optimal patient outcomes [211]. Such evidence alongside studies describing the utility of current extrication methods may prompt change in national and international guidance which defines current extrication practice [211,281]. Very little is known about casualty experience during the entrapment phase of an MVC [295–298]. Obtaining patient views and experiences via engagement and representation is a fundamental step in this process of developing and describing evidence-based practice [15]. This is not found in current operational guidance, and evidence which describes patient experience of entrapment is extremely limited [252].

The aim of this project is to capture, interpret and understand the patient experience of entrapment and extrication to support and enable the development of patient-centred, evidence-based extrication guidance.

Methods

This study used purposeful sampling of patients who had undergone extrication, utilising a semi-structured interview guide to explore patient's experience of extrication. We report this study with reference to COnsolidated criteria for REporting Qualitative research (COREQ) guidelines [299].

Research team and reflexivity

This study was designed and developed by TN and WS. TN is an experienced clinician who attends extrication in the prehospital and emergency department phases of treatment. TN has trained alongside rescue services and has published research on extrication practices with a wide array of methodologies. WS is a paramedic and university based academic; his interests include emergency medicine systems and qualitative research. WS has experience with the extrication and management of patients during clinical practice.

All interviews were conducted by an experienced qualitative health researcher (JB). She also has psychotherapeutic skills, which were deemed useful for this sensitive area. Although experienced in pre-hospital care research she did not have any specific training or experience in relation to extrication and had not experienced extrication herself. The interviewer had not met any of the participants professionally or socially and did not liaise with the candidates prior to the interview other than to confirm details of consent and the administration of the interview.

TN introduced the study to participants and conducted the informed consent process.

Study design

Participant selection: All participants had undergone extrication with the support of rescue or emergency services. Participants were nominated and approached by either the Patient Liaison Clinicians of the Devon Air Ambulance or 'Aspire' a Spinal Injury support charity. Eligible participants were informed by email or in conversation about the study methods and intention. Those willing to engage further, consented to their contact details being shared with TN. TN contacted potential participants and delivered the Participant Information Sheet (PIS) and consent form by email or post. After familiarisation with the study details TN answered any additional questions. Once happy to proceed, they completed and returned the consent form to TN. With permission, participant details were then shared with the interviewer to arrange an interview.

A convenience sample based on participant availability was collected. Interviews were reviewed by TN and WS during the collection process to collate themes and identify if saturation had occurred.

Setting

This study was conducted in the UK. Participants identified by the Devon Air Ambulance had been treated by the air ambulance critical care team. Participants identified by Aspire had sustained a spinal cord injury before or as a result of the accident under consideration. The interviews were delivered over a secure online videoconferencing service (Zoom, Zoom Video Communications Inc, California US, Version 5.0) or by telephone. The participants engaged with the interviews from a quiet place of their choosing. Only the interviewer and participant were present during the interviews.

Data collection

TN developed a semi-structure interview guide based on themes identified in the literature and from personal clinical experience (supplemental material). Domains from a literature review identified the importance of pain control, the noise of extrication and the risk of hypothermia, these domains were incorporated into the interview guide [11,102,105]. The guide was modified in subsequent interviews if new themes emerged. Interviews lasted between 20 minutes and one hour. Interviews were recorded using the secure recording capability of the data collection platform and then transferred securely for transcribing by a professional transcription service. TN reviewed the transcripts and identified themes for consideration which were discussed with the interviewer JB prior to the next interview.

Approvals

Ethical approval for this study was granted by the University of Plymouth (19/20-1288) and the University of Cape Town's Human Research Ethics Committee (182\2021). Participants were specifically consented for participation, recording and secure sharing of their data. Participant withdrawal was possible until anonymisation and transfer of data for transcription as individual participants could no longer be identified.

Recordings were deleted following data analysis. Anonymised transcriptions and patient details were not shared outside of the direct research team.

Data Analysis

Following immersion in the data, transcripts were subjected to descriptive content analysis. Nvivo 12 (NVivo qualitative data analysis software; QSR International Pty Ltd. Version 12.6.1, 2018) was used to identify specific meaning units, which were then condensed, coded and categorised. Codes were reviewed, modified where necessary and corroborated by the authors. As new categories emerged from the data an inductive approach was used to develop these [300,301]. TN, WS and JB met to discuss codes, categories themes and triangulate their understanding of these [302]. Following discourse themes, sub-themes were further identified, refined and incorporated.

Trustworthiness

As described by Shenton *et al.*, trustworthiness includes credibility, transferability, dependability and confirmability [303].

Credibilit*y* was maximised through i) the adoption of appropriate, well recognised research methods, ii) ensuring the research team had no influence over the sampling of individuals serving as informants iii) providing multiple opportunities for participants to decline nor reporting whether they participated (or not) to the recruiting organisation. The nature of the questions and opening statement are designed to encourage participants to be frank and open with interviewer, iv) the use of iterative questioning at the discretion of the interviewer v) Maximising data quality and accuracy by using a professional transcription service and with internal quality checks vi) By triangulation of the results between TN, WS and JB.

Transferabilit*y* was enhanced through the provision of detailed background information to ensure that the reader had appropriate context to understand if the findings could be applied in their setting.

The reader was supported in judging dependability by ensuring that the research process was logical and well documented following the COREQ guidelines[299].

The principal researcher (TN) interrogated any bias he might have in this project and these were recorded and detailed prior to the collection of data. Transcribed data were checked and triangulated by other authors to further support confirmability.

Appropriately detailed methods are provided along with a recognition of the shortcoming of such methods in the 'discussion' section of this paper.

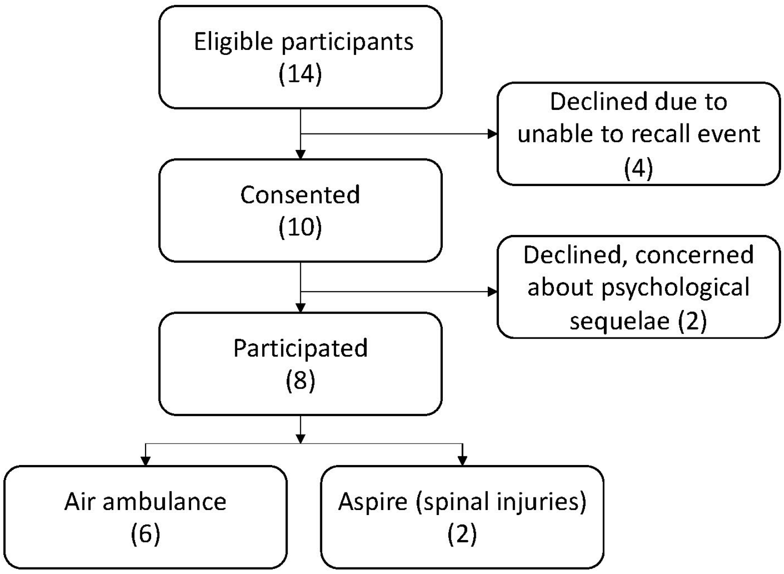
Patient and public involvement

A central tenant of this research is understanding the patient experience; patients were therefore intrinsically involved. Patients were not involved in the design or reporting of this research.

Results

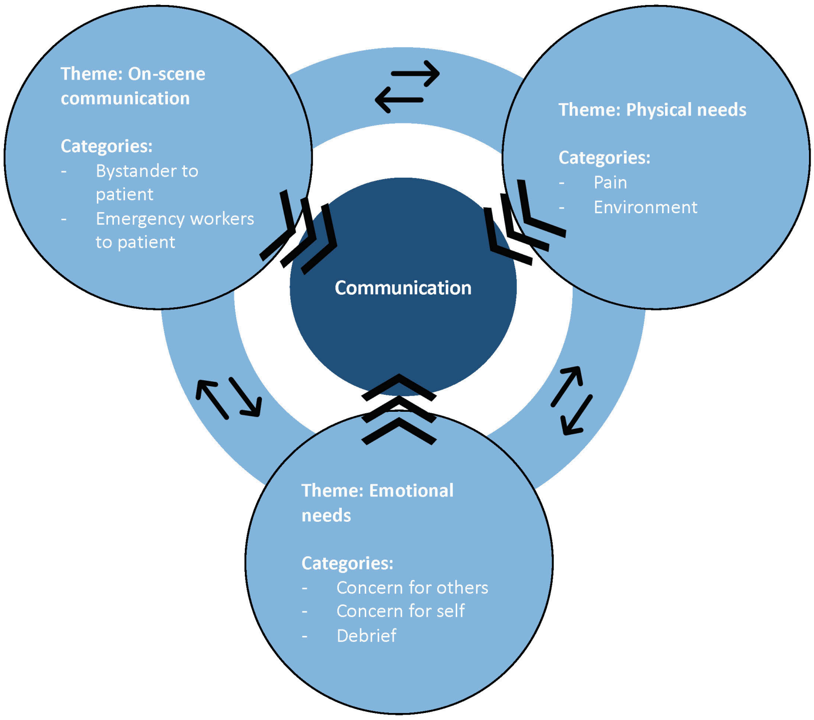
A total of ten participants consented to take part in the interviews of which eight successfully participated. The two participants who did not wish to be interviewed raised concerns related to the potentially negative psychological effects of recounting their experience. A further four participants met the inclusion criteria for the study but did not feel they could progress further as they had very limited or no memory of their accident or their experience of extrication (Figure 10.1).

FIGURE 10.1: PARTICIPANTS, RECRUITMENT AND PROGRESSION TO INTERVIEW



Despite a diverse range of participants common categories and themes emerged across the group (Figure 10.2). This analysis resulted in one superordinate theme, that of communication. An additional three subordinate categories within this theme were identified: external environment, physical needs and emotional needs.

FIGURE 10.2: THEMES AND SUB-THEMES



The main theme across all participants was that of communication; successful communication resulted in a sense of wellbeing and where communication failures occurred this led to distress. The sub-themes of on-scene communication, physical needs and emotional needs and their component categories are presented below.

On-scene communication

This theme relates to instances where the communication on-scene whilst the participant remained trapped impacted upon their experience. The categories include 'bystanders to patient' where direct and indirect communication with bystanders at the scene of the accident was important and 'emergency workers to patient' which describes the on-scene communication with the patient from both rescue workers and clinicians.

Bystanders to patient

Participants were universally grateful for assistance and support of bystanders. Common themes included the reassurance that came from bystanders calling for professional help and the provision of companionship both at an early phase of an incident and beyond. Some bystanders remained outside of the vehicle and provided reassurance and coaching to participants in distress:

I remember talking to her through the window, and she kept saying, just stay with it; you're fine; you’ve got a good colour. And I was going, I can't breathe, I can't breathe, I can't breathe. And she was just saying, just keep calm; you're doing well; you're fine; you're doing all right; you’ve got a good colour; you're getting oxygen; you're all right (P6)

Often participants were joined in the vehicle by a bystander. This companionship whilst in the vehicle was important to our participants and led to a sense of safety.

“So, I was trapped, trapped under there as well. Came to, there was the nurse in the car... So, she came in. And then in then in the car behind her, were three paramedics from the Royal Marine base.… the marines, they actually stayed in the car till I was taken out. And so they kept talking to me the whole time.. .. I definitely felt looked after. Yes. Very safe. (P3)

Participants expressed a need for companionship whilst in the vehicle and were keen for this companionship to remain throughout the process of extrication and when the companion might be leaving, requested that they stayed.

“*Yeah, they calmed me down completely. I can remember … she was gonna get out of the car, and I said to her, y'know, do you think you could stay with me? And from that moment on she didn’t leave my side. (P5)*

Bystanders also offered very practical help which was useful and reassuring to participants.

“ I kept feeling like I was falling… And cos my leg was broken I was panicking cos I kept thinking my leg was just dropping. So he was holding me”-(P8)

Bystanders who were merely observing were less appreciated, particularly those taking photographs, recording footage and making these available on social media and news platforms. This was distressing for participants and their families, particularly where publication of these images led to unwanted engagement from those remote to the incident (see also section ‘Patients concern for others’).

" I had messages coming from all kinds of people that I hadn’t spoken to in ages…. It was a bit overwhelming" (8)”

<u>Emergency workers to patient</u>

Communication between emergency workers and the patient was also paramount for participant experience. Explanations were important to our participants:

“But they talked me through everything that they were going to do. Y'know, when they were gonna cut the side of the car, they said, like, you'll hear a bang. And I just felt really safe…I say I felt really looked after” (P3)

The ‘manner’ of emergency workers, particularly by creating an atmosphere of organisation, purpose and calm alongside participants led to a positive experience despite the distressing circumstances.

“they were so calm and they explained everything as they were going along. And that would be one of the things that I would say to you I found so reassuring. Well, they're calm, so … why should I panic?”(P1).

Explanations of the practical steps that were occurring and the justification for them were important in creating a positive experience for our participants.

“Very, very helpful. They told me whenever they were going to do anything what they were going to do, why they were gonna do it, sort of thing. And explained that, y'know, they wanted to cover my face because of the glass from the windscreen and everything. So I [laugh] I just was a very good girl and just sat quiet and let them get on with it.” (P5)

When participants didn’t feel listened to this was a negative experience. Participants were concerned when they were not involved in conversation which resulted in a loss of autonomy.

“They should’ve just like listened to me instead of like making their own assumptions… But it was like they weren’t listening to me. It was just like, listen to each other. I tried to explain to them I was fine.” (P7)

Similar to the positive experience of bystanders, participants appreciated the presence of emergency workers particularly when they joined them in the vehicle. Distraction from interventions or the physical environment using calming language provided relief for participants.

"Yeah, the paramedics and there was a lady.. that came and sat next to me in the passenger seat. And she just kept chatting to me the whole time, just to try and distract me. Because when they were putting the needles in and stuff, I'm terrible with needles, so she was brilliant just talking me through it, just to take my mind off it." (P8)

The presence of a companion in itself was not enough to create positive emotions. They needed to engage with the patient, offer explanations and create a connection.

"Yeah. No, they didn't speak to me once. It was like they had an ambulance driver [laughs] sit next to me while they cut the car open. But there was no, like, no name, no like conversation." (P7)

Physical needs

This theme relates to the physical needs of the participant during entrapment. The categories include 'Pain' which includes the pain experience itself and actions which improved or worsened a participant's perception of pain and 'environment' which relates to environmental factors such as temperature and the effects of weather and their mitigation.

Patients who require extrication need assessment and treatment to facilitate this process [3]. Delivering an adequate clinical assessment will often mean undressing a patient and is normally associated with physical contact such as chest or abdomen palpation to assess for potential injury [28]. How this physical assessment occurred, the communication of explanations around it was clearly important to our participants.

"they all descend on you… they forget that you're lying there... I don't remember seeing anybody's face.. It would've been nice to see somebody's face...and they didn't tell me they were gonna cut my clothes off" (P2)

<u>Pain</u>

Several participants reported a window of time immediately following their collision where they were unaware of their injuries. During this peri-traumatic window the participants reported that they do not recall suffering pain, despite having significant injuries that would normally be associated with severe pain.

"I didn't feel that I had any injuries at the time. And I was just wanting to get out of the car. I just, you know, got to get out and um. nothing hurt straight away. It started hurting after a little while but at that point, nothing hurt." (P3)

When the peri-traumatic window passed a small number of participants reported sudden and severe pain.

"And oh, my god, it was just like being smacked in the face with a frying pan or something. The pain just went bang. And I think I just came into reality. And the pain was just horrific. I then remember saying that I can't breathe. The pain is horrific, I can't breathe. I can't breathe" (P6)

<u>Environment</u>

MVCs and subsequent extrications occur almost exclusively outdoors. This can leave patients exposed to the elements. Participants did not report being cold – this may be attributed to the mitigation measures (such as blankets) or the 'shock response'.

"And I think it was then that the paramedics arrived. And came and took over from my dad. And wrapped me up, cos I was freezing cold, cos it was back in February when it was really bitter… there was so much going on, and I think I was just too busy panicking that I didn't feel cold or pain or anything." (P8)

Emotional needs

This theme considers the emotional needs of the participants and how these needs are best supported. The categories include participants' concern for others, their concern for themselves and the value of debrief following an incident.

<u>Concern for others:</u>

Participants' concern for others was another significant theme. This concern included co-passengers in the vehicle, companion animals involved in the incident and friends and relatives at home. Participants appreciated positive, reassuring communication and practical assistance from both bystanders and rescuers in this regard.

"Yeah and the dog, I was most worried about [laughs]. Luckily I could see him in the car behind, so I knew he was safe. Yeah." (P8)

An important issue was communication between the family and friends remote to the scene and 'onlookers' (via social media) or the rescue teams. Many participants were unhappy with how their families found out about the incidents. They were particularly concerned with communication delay, the accuracy of the information that was conveyed and the negative effects of uninformed onlooker narrative on social media and news channels.

I: "So tell me about how did your loved ones get to hear about this?

This is the not good bit. My phone was in my handbag…. And I kept saying, can you please get my phone …. And I remember saying it quite a few times, to quite a few different people. They're like yeah, the police are doing that, it's all sorted; police are doing it. No, they didn't." (P3)

In a further example uninformed updates posted to social media from onlookers from scene cause considerable distress to family.

"They found a site.. that was having witness statements being given and updates.. they actually had more stress than I did. A witness wrote down that the driver is still trapped in the car and he can't feel his legs... so my family and my children were, oh my god, Dad's trapped in the car still, and he can't feel his legs" (P1)

<u>Concern for self</u>

Participants were concerned for their own wellbeing. Concerns rarely related to their own initial injuries but instead reflected concerns related to the fear of fire and of not being recognised as alive and rescued.

"I remember the sides of the car coming in. Then I was in a bubble…? And I couldn't move. I thought oh my god, they're gonna think I'm dead. Cos I'm in this bubble and I can't get out." (P6)

"Cos I said to her I've never been in a car crash, and the car was smoking. I thought the car was on fire." (P7)

<u>Debrief</u>

Participants valued post-accident planned communication from the Emergency Services. Planned follow up helped participants by acknowledging the importance of the incident as a life event.

"how good it's been that people have rung me subsequently…. it's been amazing it has been something that I found very beneficial. That I wasn't just an accident and then that was it, right, move on to the next one" (P1)

They found post-collision professional follow up useful in orientating themselves in understanding what had happened to them. However, participants found reminders of the collision in the form of photos on social media or on rescue services pages a negative experience.

"Yes I'm shocked by what happened. Yes I was shocked by the pictures." (P5)

"I've not been strong enough to see those photos yet. I've not seen them. So I don't know exactly how they got me out or what they had to do." (P6)

Discussion

This study demonstrates that most participants were generally satisfied with their experience of extrication, despite some serious injuries. Their experience was improved by positive communication, companionship, explanations and planned post-incident follow-up. Factors which led to a poor experience were communication failures, loss of autonomy, unmanaged pain, poor communication with remote family and the negative effects of onlooker use of social media (particularly on remote family and friends).

The importance of positive communication and reassurance identified in this study as an important aspect of psychosocial care are common themes in hospital studies looking at the acute treatment of injured patients [304,305]. In the published prehospital literature, there is generally a focus on the practical rather than the psychosocial aspects of emergency care and improved patient experience (e.g. the treatment of pain) which is at odds to the needs identified by our participants [306]. The positive role of planned companionship for patients across a range of healthcare environments is well described, however, the benefits of unplanned, ad hoc companionship from persons unknown to the patient as in this study, is not [307–309].

The role of bystanders in supporting injured patients is often considered in the important task of contacting professional help and providing practical interventions [127,310]. Heidari *et al.* discussed the practical aspects of bystanders aiding with the injured but noted that their ability to provide further support may be inhibited by emotion [311]. Alternative themes in the literature include the 'stress' experienced by bystanders leading to an urge to act in ways that may be potentially harmful to the patient e.g., dragging them from their vehicles or the fear of getting something wrong leading to inaction [87,312]. This was notably different from the perspectives of our participants. The experience of the actions of engaged bystanders (as opposed to those of onlookers) was universally positive as recounted by our participants. Bystanders could be engaged to provide beneficial support to trapped patients by the inclusion of direction in 'first aid' courses or from direct instructions from the call handler when they make contact with the emergency services to report an MVC.

The importance of debrief and assisting with fragmented memories and narratives are demonstrated in our findings and the work of others [313]. Psychological sequelae following MVCs are high, this is in keeping with the participants who consented for this work and then declined to undertake the interview stage [73]. The participants who reported positive emotions associated with debrief and follow up had had their accidents relatively recently (within 3 months). More research is needed to understand the long-term benefits and to identify any potential harms which may follow debriefing by associated clinical and rescue professionals (such as paramedic led patient liaison services). Other researchers have found debriefing of MVC victims delivered by a professional psychologist, contributes to negative long term psychological health outcomes [73].

The peri-traumatic window experienced by our participants and variable pain experience is consistent with the findings of others [245]. Our participants benefitted from analgesics which is consistent with the findings of effectiveness studies [314].

When our participants experienced fear, it tended not to be in relation to their injuries or the future impact of such in injuries, but fear of further injury – particularly a fear of fire. This fear of fire is common to other qualitative analysis of patients following MVCs, though the actual incidence of vehicle fire caused by road traffic collisions is vanishingly small [87,315]. Reassurance specifically to address this fear should be considered by rescue teams.

This study is limited as it is single centre and only featured English speaking adults from the UK. The transferability in respect to lower- to middle-income countries and other patient groups (especially children) may be limited. Further research to address these groups should be considered.

The results of this study are useful in informing guidance for professional rescuers and the lay persons who have the potential to be bystanders. Instructions could be given to bystanders who call the emergency services or incorporated into first-aid courses.

Suggested behaviours and practices for adoption by clinical and rescue teams are included in Box 10.1.

Box 10.1: Suggested behaviours for rescue teams performing an extrication:

Communication and companionship for entrapped patients should be designated to a specific staff member who if safe to do so and not an impediment for extrication should join the patient in the car

An 'extrication buddy' should be assigned to explain the procedure, ensure companionship and provide reassurance to the patient whilst entrapped

Communication with the patient should be clear and use accessible lay language

Patients should be reassured that their co-occupants are safe (including animals)

If conscious, patients should be allowed to communicate with their family members

Where possible the ability of the public to photograph the vehicle and the patient should be minimised

Attempts should be made to minimize onlooker photographer and post-accident photos on social media and news channels

Rescuers and their affiliated organizations should not post extrication related photos on their social media channels or websites

Where possible planned follow up should be offered to patients

NB: These statements have been utilised in a Delphi study to aid translation to practice.

Future work should focus on understanding how to empower bystanders to safely assist trapped patients and ensuring that patients and the public are regularly involved in the development of guidance which informs the rescue services approach to extrication. Public education programmes should deter onlookers from photographing or filming patients in their vehicles or reporting information from scene.

The principles outlined in Box 1 should be considered for multi-professional adoption and the impact of their utilisation carefully monitored. The medium- and long-term sequelae of debriefing by rescue services should be assessed and reported.

Conclusion

Extrication experience was improved by positive communication, companionship, explanations and planned post-incident follow-up. Extrication experience was negatively affected by failures in communication, loss of autonomy, unmanaged pain, delayed communication with remote family and onlooker use of social media. Recommendations are made which will support a positive patient centred extrication experience.

Section Discussion

The conception, delivery, analysis and inclusion of the paper featured in this chapter has ensured that the EBM principle of consideration of ‘patient values and preferences’ has been meaningfully adhered to and has added value to this thesis through an enhanced understanding of the patient perspective.

In retrospect, it may have been valid to include those patient’s with no or very little recollection of the incident at point of consent. The interview process itself may have surfaced memories which may have offered additional themes to this chapter. Patients’ memory may have been affected by actual or sib-clinical traumatic brain injury, the effects of analgesia and dissociative medications such as ketamine or as a (protective or harmful) psychological sequalae of the event [316–318]. Further work considering the potential for the early administration of psychoactive substances (such as ketamine) to influence memory and PTSD post incident is warranted.

There were a (unknown) number of patients who were approached about the study who declined to take part and a further two who initially consented but withdrew consent prior to interview due to concerns related the psychological sequelae of participation. It would be valuable to consider reapproaching this group for interview in the future to investigate if they offer a further perspective on the extrication experience.

The finding in relation to the negative effects of onlooker photographs and social media were not predicted prior to initiating the study. Many of the patients raised concern in relation to families discovering their accident via social media (and assuming the worse), miscommunication and social media being used as a tool post-accident to attract uninvited and emotionally taxing communication. A review of the medical literature could find no papers which reported this issue, however the phenomena of “gawking” is regularly reported in the media [319]. Some countries have introduced legislation supported by novel solutions to reduce this issue, with a pilot scheme in Germany introducing QR codes on the sides of rescue vehicles, bags and equipment which when picked up by a smart phone or camera ‘text’ the user an instruction to stop using their camera [320].

The paper in this chapter recommends suggested behaviours that may contribute to a positive patient experience of entrapment and extrication (Box 1). A key theme of these behaviours (and the paper as a whole) is that of communication and the importance of building a meaningful connection with patients. This connection alongside ‘human’ communication has the advantage of being of a low economic cost, however, such skills are a challenge to teach and maintain [321,322]. This ‘intervention’ will benefit from being well defined, taught in a structured way to all professionals with frequency exposure to MVCs, with the role being assigned to a trained individual (or individuals in the case of multiple patients) at each incident.

Key messages: Section 4

- The experience of entrapped patients was improved by positive communication, companionship, explanations and planned post-incident follow-up.
- The experience of entrapped patients was made worse by communication failures, loss of autonomy, unmanaged pain, poor communication with remote family and the negative effects of onlooker use of social media.
- Behaviours are suggested which will contribute to a positive patient experience (Box 10.1)

Section 5:

Expert Clinical Judgement

Section Introduction

In this section we use expert clinical judgement to interpret the literature already available (Section 2) with the new knowledge generated from this thesis (Section 3) and considering patient values and preferences (Section 4).

Choice of consensus finding technique:

The three most widely used consensus finding methods in the medical literature are nominal group technique, consensus finding conference and the Delphi study [323]. The Delphi technique was chosen for its advantages over other techniques in the context of this research:

- It supports many members to take part asynchronously at their own pace and therefore was accessible to those with clinical or operational backgrounds (e..g working shift work)
- It requires no face-to-face interaction and therefore was deliverable in the context of the Covid-19 pandemic
- It allows each member to contribute anonymously and therefore mitigates power dynamics which may be hierarchical or between the disciplines

Choice of subject matter experts (SMEs)

This Delphi asked stakeholder organisations associated with prehospital clinical care and operational / rescue practice to nominate representative SMEs utilising their preferred methods. This route of identifying SMEs was used to minimise the selection bias which can come from selection of SMEs from the investigators peers / professional circle. SMEs were required to have five years of clinical or operational experience to ensure grounded expertise in the management of entrapped patients. SMEs of other backgrounds were considered in the planning stages of the study, including police service representatives, accident investigation specialists, spinal trauma specialists, those with expertise in car design and patient/ public representation. There was already a broad range of potential statements to consider and an awareness that the primary purpose of the study was the pragmatic translation of a scientific evidence base into a patient focused pragmatic extrication approach, as such the disciplines considered for SMEs (and therefore the stakeholder organisations) were limited to those of rescue or clinical backgrounds.

The next chapter which makes up the remainder of this section present an original paper which is reproduced in full but formatted to provide consistency throughout this thesis. This section ends with a discussion of the contributory chapter and relates their findings and outcomes to the thesis as a whole.

Chapter 11: A Delphi study of rescue and clinical subject matter experts on the extrication of patients following a motor vehicle collision

Declaration from author and co-authors

The following co-authors contributed to the publication: Fenwick R, Smith JE, Dayson M, Carlin B, Wilson M, Wallis L, Stassen W.

Contributions of the authors were as follows: All authors named met the ICMJE criteria for authorship. All authors contributed to the conception and study design. Initial analysis and manuscript draft by TN. All authors have contributed to and approved the manuscript.

The extent of contributions from each person are as follows:

- TN: 55%
- RF: 10%
- JES: 10%
- MD: 2.5%
- BC: 2.5%
- MW: 2.5%
- LW: 2.5%
- WS: 15%

Given the large number of co-authors, the principal investigator and the supervisor hereby sign for approval on behalf of the group, in accordance with the UCT Doctoral Degrees Board guideline titled, “GUIDELINES FOR THE INCLUSION OF PUBLICATIONS IN A DOCTORAL THESIS.”

	25 July 2022
Tim Nutbeam	Date
	25 July 2022
Willem Stassen	Date

Abstract

Background

Approximately 1.3 million people die each year globally as a direct result of motor vehicle collisions (MVCs). Following an MVC some patients will remain trapped in their vehicle; these patients have worse outcomes and may require extrication. Following new evidence, updated multidisciplinary guidance for extrication is needed.

Methods

This Delphi study has been developed, conducted and reported to CREDES standards. A literature review identified areas of expertise and appropriate individuals were recruited to a Steering Group. The Steering Group formulated initial statements for consideration. Stakeholder organisations were invited to identify subject matter experts (SMEs) from a rescue and clinical background (total 60). SMEs participated over three rounds via an online platform. Consensus for agreement / disagreement was set at 70%. At each stage SMEs could offer feedback on, or modification to the statements considered which was reviewed and incorporated into new statements or new supporting information for the following rounds,

Results

Sixty SMEs completed Round 1, 53 Round 2 (88%) and 49 Round 3 (82%). Consensus was reached on 91 statements (89 agree, 2 disagree) covering a broad range of domains related to: extrication terminology, extrication goals and approach, self-extrication, disentanglement, clinical care, immobilisation, patient-focused extrication, emergency services call and triage, and audit and research standards. Thirty-three statements did not reach consensus.

Conclusion

This study has demonstrated consensus across a large panel of SMEs on key areas of extrication practice that will provide a foundation for the development of multidisciplinary consensus guidance for this subject area.

Background

Approximately 1.3 million people die each year globally as a direct result of motor vehicle collisions (MVCs) [1]. Following an MVC some patients will remain trapped in their vehicle; these patients have worse injuries and are more likely to die than their not trapped counterparts [211]. Patients who are trapped may require assistance in leaving their vehicle; this assistance is termed 'extrication' and is often delivered by the rescue services [3]. Extrication may be simple, such as releasing a stuck door, or complex, with specifically designed tools and techniques being used to alter the internal and external structures of the vehicle [3]. The current standard approach to extrication prioritises absolute movement minimisation which contributes to prolonged extrication times [19,141,252]. Such 'traditional' approaches to extrication have recently been challenged by evidence demonstrating the relative rarity of unstable spinal injury or spinal cord injury compared to other time-critical injuries[211]. In addition biomechanical studies in healthy volunteers have demonstrated that rescue service extrication techniques cause more movement than self-extrication further questioning the accepted approach to extrication [247,281,286].

Given this new evidence, we need to reconsider the current approach to extrication. The current evidence base is wide and diverse, including a large variety of experimental techniques from a broad range of disciplines. These approaches and disciplines include, but are not limited to; rescue services descriptive accounts, biomechanical analyses, clinical case reports, case series, expert opinion, patient experience, crash investigation reports, road safety expert opinion, car design literature and others. The complex nature and wide variety of potential circumstances and subsequent energy transfer that occurs in an MVC, the number, demographics and susceptibility to injury of the patients involved, their injuries and the availability of each aspect of the multi-professional response makes the design and delivery of traditional 'clinical' trials in this area an impractical challenge.

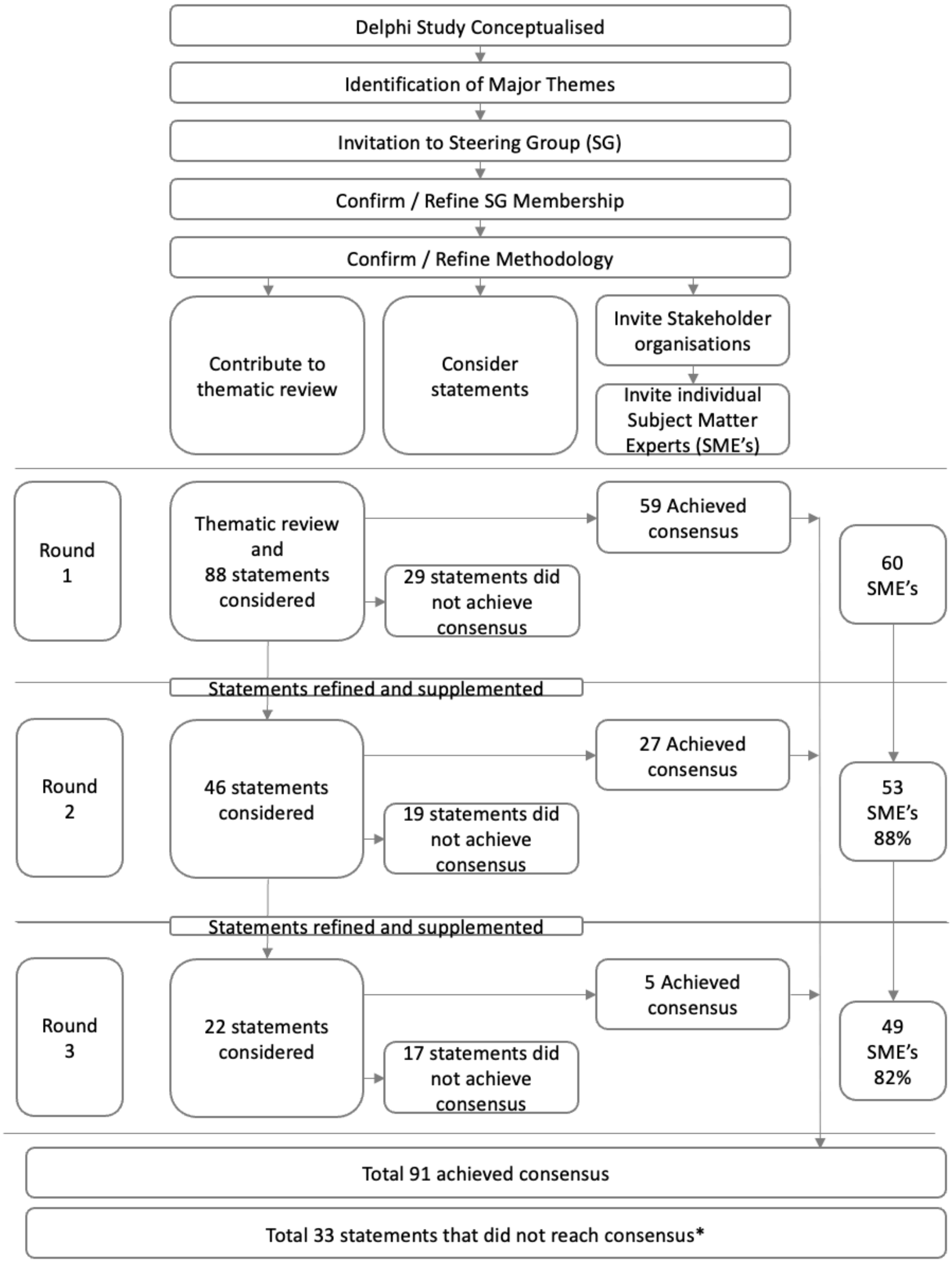
The diverse evidence base, requirement for pragmatic expert translation of evidence to practice and the need to achieve agreed multi-professional consensus makes this subject area highly suitable for iterative multi-stage consensus research techniques, such as a Delphi study [324,325].

The aim of this Delphi study is to develop multi-professional consensus on the evidence-based approach to extrication.

Methods

This Delphi study has been developed, administered and reported to the guidance on Conducting and Reporting Delphi Studies (CREDES) standards [324]. The methods are summarised in Figure 11.1.

FIGURE 11.1: SUMMARY OF METHODS AND PROGRESSION OF STATEMENTS AND SMEs THROUGH THE STUDY



*Of the 33 statements that did not achieve consensus, 19 were withdrawn from the process as replaced by other statements

The principal researcher (TN), through a review of the literature identified key areas of expertise that should be represented in a Steering Group for a study in this area of practice. This included individuals with expertise in extrication, prehospital care, trauma care, neurotrauma and representatives of patients with spinal cord injury. Experts with an interest in each of these areas were identified and recruited to offer guidance to the principal researcher within their areas of specialist interest, provide feedback on methodology and process, aid in the production and refinement of statements for the Delphi group and ensure methodological rigour. Joining the steering group excluded an individual as a participant in the Delphi (or subject matter expert, SME).

The Steering Group identified professional organisations that are key stakeholders in UK extrication practice. Stakeholder groups identified were the National Fire Chiefs Council (NFCC), the United Kingdom Rescue Organisation (UKRO), the National HEMS Research & Audit Forum (NHRAF), the College of Paramedics (CoP), the Pre-Hospital Trainee Operated Research Network (PHOTON) and the Faculty of Prehospital Care (FPHC). Each stakeholder organisation was invited to identify up to ten representatives (SMEs). To qualify, SMEs needed to have at least five years of operational experience of delivering extrication or caring for patients during or post entrapment.

Statements for consideration originated from the current evidence base (including unpublished work reporting patient experience) and were proposed by the Steering Group and other stakeholders. All responses were collated and similar statements were collapsed. All materials, including surveys, statements and other written information were reviewed by the Steering Group and subsequently piloted with a multi-professional representative group of SMEs prior to further distribution.

The Delphi was conducted over three rounds, each of which were designed and delivered through the web-based platform Jisc online surveys (JSIC, https://www.onlinesurveys.ac.uk/ 2022). Identified SMEs (60 total) were provided with details of this Delphi study, the statements for consideration, an evidence synthesis (available as supplementary material), an invitation to participate in the study and an online consent form. Throughout the study the anonymity of the SME group was preserved. In each round, SMEs were invited to review the evidence synthesis for each domain of extrication practice and then for each statement using a three-point Likert scale (agree, neither agree nor disagree, disagree) to indicate their opinion. In addition, for each statement the SME had the option to 'opt out' if the specific question was outside of their area of expertise. For each statement SMEs had the option to provide free text feedback; including the opportunity to refine current statements and suggest alternative statements for consideration in the following round.

Consistent with previous studies, consensus was set a priori at 70% agreement or disagreement of participating SMEs [326,327]. Between each round, statements that reached consensus were removed. Statements that did not reach consensus were refined if consistent feedback indicated that this would improve or clarify the statement. Additional suggested statements were collapsed and made available in the following round. If SMEs did not participate in a round they were not eligible to participate in subsequent rounds.

The Faculty Research Ethics and Integrity Committee at the University of Plymouth (ref. 19/20-1313) and the Human Research Ethics Committee at the University of Cape Town (ref. 183/2021) approved the study.

Results

Rounds 1-3 were conducted in January and February 2022. The background and experience of SMEs are summarised in Table 11.1.

TABLE 11.1: PROFESSIONAL, EMPLOYER AND EXPERIENTIAL BACKGROUND OF SMEs

Demographic	Detail	Number	(%)
Professional background	Fire and Rescue Service	14	(23.3)
	Paramedic	30	(50)
	Doctor	15	(25)
	Nurse	1	(1.7)
Primary employer	Fire and Rescue Service	14	(23.3)
	Clinical Service	45	(75)
	Both	1	(1.7)
Clinical or operational experience	Up to 10 years	19	(31.7)
	11 to 15 years	10	(16.7)
	16 to 20 years	12	(20)
	Over 20 years	19	(31.7)

Figure 11.1 summarises the study. In Round 1, 88 statements were considered by 60 SMEs. Sixty statements achieved consensus (58 agree, 2 disagree). Free text feedback from SMEs led to three of the original statements from Round 1 progressing to Round 2 for reconsideration (with additional commentary) and the remaining 25 statements were refined and split to make a total of 46 statements presented at Round 2, where 27 statements achieved consensus and 19 did not. Following feedback in Round 2, 22 statements were presented to SMEs in Round 3 of which 5 achieved consensus and 17 did not.

TABLE 11.2: STATEMENTS ACHIEVING CONSENSUS BY THEME

Theme	Statement
Terminology	A multi-professional, standardised terminology should be developed and adopted to describe different extrication approaches and their variants
	The term "patient" is used to refer to the (potentially) injured person post MVC regardless of entrapment status
	A multi-professional, standardised terminology should be adopted to describe risks and hazards at a scene of an entrapped patient
	A multi-professional, standardised terminology should be adopted to described how badly injured and or time-critical entrapped patients are
	A multi-professional, standardised terminology should be developed and adopted to describe the entrapment status of patients (e.g. medically trapped, physically trapped)
	A multi-professional, standardised terminology should be developed and adopted to describe different extrication

	techniques as per Joint Emergency Services Interoperability Principles (JESIP)
	A multi-professional, standardised terminology should be developed and adopted to describe how rapidly a patient needs to be extricated
	Nomenclature for categories of patient: ***Not injured*** ***Minor injuries*** (evidence of energy transfer but no evidence of time-dependent injury) ***Major injury*** (currently stable but should be assumed to be time-dependent) ***Time critical injured*** (Time critical due to injury; use fastest route of extrication) ***Time critical hazard*** (Time critical due to a hazard such as fire)
Extrication goals and approach	The historical focus on absolute movement minimisation is no longer justified given information on rarity of spinal injury and frequency of other time critical injuries
	The rescuer goal in consideration of patient movement should be "Gentle patient handling"
	Minimising entrapment time should be a multi-professional goal for all entrapped patients
	Self-extrication or minimally assisted extrication should be the standard 'first line' extrication for entrapped patients who are conscious and likely to be able to stand with assistance

Extrication routes (other than self-extrication) appear to be bio-mechanically similar, so it is reasonable to choose the quickest deliverable route given the specific circumstances of the incident

Unconscious patients have high risk of significant injuries and should have an expedited extrication undertaken using ‘gentle patient handling’ techniques

Extrication goals and approach should be similar regardless of the sex or gender of a patient

Patients with acute neurological deficit (e.g. pins and needles in arms) may have time dependent pathology. They should be handled “gently” throughout and entrapment time should be minimised

FRS and clinicians should work together (as per JESIP principles) to plan and deliver a patient and rescuer centred extrication strategy

When environmental conditions permit, FRS personnel should be trained and empowered to plan and complete extrication when clinicians are not available

Self-extrication All patients should be assessed to see if they are suitable for self-extrication as the primary method of extrication

Patients with neck and / or spinal pain should be considered for self-extrication

Patients with lower limb injuries should be considered for assisted self-extrication

Patients regardless of their injuries should be assessed for suitability for (assisted) self-extrication

Patients with evidence of neurological injury (e.g. pins and needles in arms) may have a spinal cord injury. Patients in this group that can self-extricate, with or without assistance should be encouraged to do so (as this method is associated with smallest movement and shortest entrapment time)

FRS should be trained and empowered to assess patient suitability for self-extrication and assist with this if required

Patients of all ages who are normally mobile should be considered for self-extrication

Patients of all ages should be assessed for actual and potential injuries and a bespoke extrication strategy planned and delivered

Patients with suspected open book pelvic injuries should NOT be considered for (assisted) self-extrication

Contraindications to self-extrication include: i) an inability to understand or follow instructions, ii) injuries or baseline function that prevents standing on at least one leg, (specific injuries include: unstable pelvic fracture, impalement, bilateral leg fracture)

Patients without contraindications can be considered for self-extrication

Considering statements that define suitability for self-extrication, further consideration of specific pelvic related contraindications are not required

Disentanglement Patients who are physically entrapped as a result of intrusion have a high likelihood of significant injuries and as such should be considered time critical

Disentanglement should be followed by the quickest appropriate extrication type

Disentanglement should be followed by the quickest appropriate extrication type including self-extrication

Collisions where patients require disentanglement should trigger a senior FRS extrication response

Collisions where patients require disentanglement should trigger an 'enhanced' clinical care response[1]

Collisions where patients require disentanglement should trigger a 'critical-care' clinical response[2]

Entrapped patients with evidence of energy transfer (injury) should be considered to have time-dependent injuries and entrapment time should be minimised

Collisions where patients require disentanglement are associated with significant injuries to patients, as such FRS should provide an enhanced* response to such incidents. *Accepting that this term and the response will require definition

Post-extrication patients who were entrapped should be carefully and comprehensively assessed, and where appropriate, transferred preferentially to a major trauma centre

Clinical procedures such as intubation and thoracostomy should ideally be delayed until a patient has been extricated

Clinical care	Appropriate in-car interventions for the trapped patient include tranexamic acid
	Appropriate in-car interventions for the trapped patient include analgesia
	Appropriate in-car interventions for the trapped patient include oxygen
	Appropriate in-car interventions for the trapped patient include control of compressible haemorrhage
	Appropriate in-car interventions for the trapped patient include decompression of tension pneumothorax
	Clinical care should be limited to necessary critical interventions to expedite safe extrication
	Rescuers should be aware that clinical observations may prolong entrapment time and as such should be kept to the minimum required
	FRS and clinical personnel should be aware of the physical and observable signs of patient deterioration and if identified should make this known to the responsible clinician
	Patients who require volume (fluid or blood product) resuscitation are likely to have time critical injuries and their removal from the vehicle should be prioritised. In the small number of patients who

cannot be released quickly then ‘in vehicle’ fluids and /or blood products may be required

The choice of blood product (where available) and IV fluids should be led by the available evidence

Following clinical assessment, if a patients 'in-vehicle' needs can be met by FRS personnel then clinicians are recommended to withdraw from the vehicle to enable an efficient extrication

Within an appropriate system of training and governance, FRS personnel should be enabled to deliver in-vehicle clinical interventions that assist with extrication and mitigate avoidable patient harm

FRS training in clinical care for entrapped patients should be standardised

Immobilisation	Kendrick Extrication Devices prolong extrication time and their use should be minimised
	Cervical collars should be loosened or removed following extrication as dictated by clinical assessment
	Long boards are an extrication device and are not suitable for patient carriage beyond the immediate extrication phase
	Pelvic slings should not be applied to patients until they have been extricated
	During the initial call to emergency services, patients should be asked to self-extricate if they are able to do so and the environment is considered safe

	During the initial call to emergency services, bystanders should be advised NOT to assist patients with a decreased conscious level from the vehicle unless there is an immediate threat to life
	Call takers identifying an MVC with suspected entrapment or patients requiring disentanglement should use an appropriately developed algorithm or call interrogation to identify the most appropriate response
Patient focused extrication	Communication and companionship for entrapped patients should be designated to a specific staff member who, if safe to do so and not an impediment for extrication, should join the patient in the car
	Where possible, patients should be referred to by name
	Where possible the patient should be engaged in discussion and explanation around extrication strategy and their role in this process
	An ‘extrication buddy’ should be assigned to explain the procedure, ensure companionship, and provide reassurance to the patient whilst entrapped
	Communication with the patient should be clear and use accessible lay language
	Where possible the ability of the public to photograph the vehicle and the patient should be minimised
	Attempts should be made to minimize onlooker photography and post-accident photos on social media and news channels

Rescuers and their affiliated organizations should not post extrication related photos on their social media channels or websites

Patients should be reassured (when true) that their co-occupants are safe (including animals)

If conscious, patients should be allowed to communicate with their family members (including remotely using their phones)

The potential harmful effects of social media interaction should be notified to the public / onlookers (see QR code campaign)

Emergency Services Call and Triage

On initial emergency services call attempts should be made to clarify entrapment status

On initial emergency services call attempts should be made to clarify entrapment status

Consideration should be given for call back, video from scene and other modalities to enhance the fidelity of triage response

Collisions identified during emergency services call as potentially requiring disentanglement should trigger a senior FRS extrication response

Collisions identified at emergency services call as potentially requiring disentanglement should trigger an expert FRS extrication response

Collisions identified at emergency services call as potentially requiring disentanglement should trigger an 'enhanced'[1] clinical care response

	MVC with suspected entrapment should warrant an immediate response triage category for prehospital medical services
	A standard multi-agency MVC trauma message should be developed to ensure the correct resources are deployed
	MVC with suspected entrapment should warrant an immediate response triage category for prehospital medical services
	FRS training in clinical care for entrapped patients should be standardised
Audit standards and Research	Audit standards should be developed with patient and public engagement
	Multi-professional datasets should be developed to enable research and audit
	Multi-professional datasets should include patient entrapment status
	Multi-professional datasets should include how badly injured and or time-critical entrapped patients are
	Multi-professional datasets should include different extrication approaches and their variants
	Multi-professional datasets should include entrapment time
	Multi-professional datasets should include in-car patient care and its timing

	Multi-professional audit standards should be developed to improve quality of patient care and extrication practice
Rejected statements	The rescuer goal in consideration of patient movement should be "Absolute movement minimisation and mitigation" (REJECTED)
	Cervical collars should be used where available on all patients as a movement minimisation tool (REJECTED)

1 Enhanced care: Enhanced care is a term used in the UK to describe a wider scope of practice above that of a non-specialist paramedic. Enhanced care may be delivered by specialist or advanced paramedics (and other clinicians) and would normally include skills such as sedation a wider choice of analgesia, enhanced decision making and other interventions.

2 Critical care: Critical care is a term used in the UK to describe a wider scope of practice above that of enhanced care. Critical care is normally delivered by a team including specialist / advanced paramedics (or other appropriate background) and a doctor. The critical care skill set normally would include anaesthesia, surgical skills and access to blood product resuscitation.

Discussion

This Delphi study achieved consensus on 91 statements in an area of previously limited multidisciplinary, evidence-based guidance. These statements will provide a vital foundation for the development of multidisciplinary consensus guidance and best practice standards for the extrication of patients trapped in motor vehicles following a collision.

A key principle agreed by the SMEs identifies that operational and clinical team members should work together to develop a bespoke patient centred extrication plan with the primary focus of minimising entrapment time. The SMEs rejected the historical focus on absolute movement minimisation and instead recommended gentle patient handling for all patients independent of actual or suspected injuries. The SMEs encouraged FRS team members to take an active role in assessing patients, delivering clinical care and enacting extrication plans (including self-extrication). Inclusion and exclusion criteria for self-extrication or minimally assisted extrication were identified and agreed.

SMEs agreed that incidents where a patient may require disentanglement are complex and associated with a high morbidity and mortality and as such attempts should be made to identify such incidents at initial call to the emergency services and an 'enhanced' FRS and clinical response should be dispatched.

SMEs supported FRS and clinical services to deliver clinical care during entrapment and agreed that this care should be limited to necessary critical interventions to expedite safe extrication. Rescuers should be aware that clinical observations may prolong entrapment time and as such should be kept to the minimum and FRS and clinical personnel should be aware of the physical and observable signs of patient deterioration and share this information.

Consensus was agreed on several principles related to immobilisation, including advising that Longboards should not be used beyond the extrication phase, the use Kedrick Extrication Devices should be minimised and that pelvic sling devices should not be applied to patients until extrication had been completed. The use of cervical collars was one of the more contentious areas but SMEs agreed that collars should only be used following a clinical assessment and that they should be loosened or removed following extrication.

SMEs recognised the importance of building a connection with patients by explaining actions and using names. Communication advice included providing reassurance to patients as to the safety of their co-occupants and providing an 'extrication buddy' to provide in-vehicle companionship and explanations. SMEs recommended that rescue teams should not publish extrication related imagery to social media or other outlets and that prehospital providers should minimise the ability of the public to view the accident, take photographs or record videos.

SMEs agreed that multi-professional datasets should be developed with patient and public engagement and these data sets should include entrapment status, entrapment time, injuries, extrication approach and clinical care provided.

SMEs reached consensus in Round 1 in all the statements in the domain areas: 'Patient focused extrication' and 'Audit standards and Research'. Consensus was also reached following Round 1 across all statements in the theme areas: 'Terminology', 'Extrication Goals and Approach' and 'Patients requiring Disentanglement'. Consensus was not achieved for some of the remaining domain areas with the most contentious being the risk stratification of patients for potential cervical spinal injury, which patients should have a collar applied, and which professional groups should be providing "in vehicle" clinical care for those that remained trapped. In general terms the SMEs were quicker or more likely to reach consensus in areas of practice where there was little evidence available or there was no current guidance e.g. patient focused extrication (supplementary material). When there was more evidence available or in areas where there is current (often contradictory) guidance; for example, which patients benefit from cervical collars, the SME's less frequently achieved consensus [100,247,281,286]. This tension was displayed by more SME's choosing to 'opt out' of the evidence rich statements, but the divergence in opinion of those that did participate remained consistent through the 3 rounds.

Consensus was harder to achieve in areas where professional roles and patient 'ownership' needed to be considered. Historically medical care has been delivered by clinicians with a health care background with rescue workers only offering minimal clinical assessment and interventions [252]. Recently in clinical and operational practice these boundaries have become more fluid with rescue services offering more clinical development to their personnel [263]. The statements in this Delphi considered the role of rescue services in delivering this care which was met with strong and diverse opinions. Through the rounds of the Delphi, the purpose of the statements was clarified, this along with clearer alternative statements led to consensus being achieved.

The utilisation of the CREDES Delphi standards for this study ensured that it was conducted and reported to an appropriate standard [324]. The SMEs demonstrated a high participation rate in the process with 82% of the original SMEs completing all three rounds. This Delphi was unusual both in the high number of statements presented to the SMEs and the high level of concordance between the SMEs leading to many statements reaching consensus. We took several steps to ensure that our SME selection was robust, unbiased and with minimal sampling bias, but our SMEs may not be truly representative of wider expertise in this subject area, and this may affect the external validity of our results. All SMEs were drawn from a UK rescue service or prehospital clinical background and therefore these results may not be valid in countries with significant differences in availability or structure of rescue or clinical provision. It may be appropriate to reproduce some elements of this Delphi for settings which are notable different e.g. lower and middle income countries or military environments.

Following this Delphi, further work will be needed to support the translation of the principles into practice. Some domains from the Delphi will require further clarification;

the SMEs identified the following areas for further consensus work: FRS clinical training (87.8%), collars and immobilisation (75.5%), EMS call handling and dispatch (73.5%), and self-extrication (63.3%).

A key next step in the consensus building process will be bringing together senior representation from the stakeholder organisation involved in this Delphi to ratify the summary output. This summary output will provide a set of principles (a blueprint) on which new discipline specific guidance can be written and translated into practice.

The principles established in this Delphi benefit from having minimal financial costs associated with bringing them into practice. We envisage the main barrier to adoption of new guidance will be overcoming the institutional and individual inertia established through 50 years of movement minimisation based clinical and operational practice. The stakeholders represented in this Delphi will need to continue to work together to refine these principles for guidance, learn and revise with feedback from early adopters and ensure commonality of language and timelines for the establishment of the new guidance.

Conclusion

This study has demonstrated consensus across a large panel of multidisciplinary SMEs on many key areas of extrication and related practice that will provide a key foundation in the development of multidisciplinary consensus guidance for this subject area.

Section discussion, summary and adoption

Following the drafting of the Delphi paper above, a summary paper was prepared and distributed to the stakeholder organisations:

- National Fire Chiefs Council (NFCC),
- United Kingdom Rescue Organisation (UKRO),
- National HEMS Research & Audit Forum (NHRAF),
- College of Paramedics (CoP),
- Pre-Hospital Trainee Operated Research Network (PHOTON)
- Faculty of Prehospital Care (FPHC).

The purpose of the paper was to offer an accessible summary of the consensus and to act as a mutually agreed set of principles from which to draft organisation specific guidance. The initial aim had been to produce a single guideline document that fulfilled the education, communication and legislative needs of each organisation; however this proved impracticable due to the wide range of conflicting requirements for approach, presentation, content, language and formatting between the stakeholder groups.

Each organisation was asked to offer feedback on the document which led to small iterative changes. All stakeholders approved the final document.

This paper is reproduced verbatim over the following pages:

Principles for the basis of guidance for the care of patients who are trapped following a motor vehicle collision (MVC)

Aim

This document summarises the results of a multidisciplinary consensus process. This document should be used as a set of principles for each stakeholder organisation to adopt and if necessary develop guidance for their members.

The stakeholder organisations below have all contributed to this consensus finding process

Background

Approximately 1.3 million people globally each year die as a direct result of motor vehicle collisions (MVCs) [1]. Following an MVC some patients will remain trapped in their vehicle; such patients have worse injuries and are more likely to die than their not trapped counterparts [211]. Patients who are trapped may require assistance in leaving their vehicle, this assistance is termed 'extrication' [3]. Extrication may be simple, such as releasing a stuck door, or complex; with specifically designed tools and techniques being implemented to alter the internal and external structures of the vehicle [3]. The current standard approach to extrication prioritises absolute movement minimisation which contributes to prolonged extrication times [19,141,252]. Recent evidence has demonstrated the relative rarity of unstable spinal injury or spinal cord injury compared to other time dependent injuries [211]. Additional studies have made available biomechanical data establishing that movement minimisation techniques used by rescue services.[211,247,281,286].

Given this new evidence, a multidisciplinary group of subject matter experts representing this group of stakeholder organisations worked together using consensus building Delphi techniques to consider guidance for the care of trapped patients. This process resulted in widespread consensus which is summarised in this document.

Principles

Operational and clinical team members should work together to develop a bespoke patient centred extrication plan with the primary focus of minimising entrapment time.

Independent of actual or suspected injuries patients should be handled gently. A focus on absolute movement minimisation is not justified.

When clinicians are not available, FRSs should where necessary assess patients, deliver clinical care and make and enact extrication plans (including self-extrication).

Self-extrication or minimally assisted extrication should be the standard ‘first line’ extrication for all patients who do not have contraindications, which are:

- An inability to understand or follow instructions,
- Injuries or baseline function that prevents standing on at least one leg, (specific injuries include: unstable pelvic fracture, impalement, bilateral leg fracture)
- All patients with evidence of injury should be considered time-dependent and their entrapment time should be minimised.

Incidents where a patient may require disentanglement are complex and associated with a high morbidity and mortality. A senior FRS and clinical response should attend such instances.

Clinical care during entrapment:

- Can be delivered by FRS or clinical services.
- Should be limited to necessary critical interventions to expedite safe extrication
- Rescuers should be aware that clinical observations may prolong entrapment time and as such should be kept to the minimum.
- FRS and clinical personnel should be aware of the physical and observable signs of patient deterioration and if identified should make this known to the responsible clinician.

Immobilisation:

- Longboards are an extrication device and should not be used beyond the extrication phase.
- Kendrick Extrication Devices prolong extrication time, and their use should be minimised.
- Pelvic slings should not be applied to patients until they have been extricated.
- Cervical collars should only be used following assessment and should be loosened or removed following extrication.

Patient focused extrication

- Build a connection with patients, explain actions, and use their name.
- Where appropriate, reassure patients as to the safety of their co-occupants and others involved in the incident (including animals)
- Provide an ‘extrication buddy’.
- Allow communication with family members or other close contacts
- Rescue teams should not publish extrication related imagery to social media or other outlets.
- Minimise the ability of the public to view the accident, take photographs or record videos. Provide education to this effect.

On initial call to Emergency Services

- Attempt to clarify entrapment status
- Attempt to identify patients who require disentanglement (and dispatch an appropriate priority senior response)
- A standard multi-agency MVC trauma message should be developed to ensure the correct resources are deployed.

Multi-professional datasets should be developed with patient and public engagement and should include entrapment status, entrapment time, injuries, extrication approach, clinical care

Terms:

FRS = Fire and Rescue Services

Disentanglement = requires the use of cutting tools to free patient

Agreed nomenclature for categories of patient

Not injured, Minor injuries (evidence of energy transfer but no evidence of time-dependent injury) , **Major injury** (currently stable but should be assumed to be time-dependent) , **Time critical injured** (Time critical due to injury; use fastest route of extrication) **Time critical hazard** (e.g. secondary to fire or other hazard)

END OF PRINCIPLES DOCUMENT

Key messages: Section 5

- Stakeholders and their nominated SME’s provided expert clinical and operational judgement to translate the available evidence into guidance.
- **The multidisciplinary principles for the evidence-based extrication of patients trapped in motor vehicles following a collision have been developed and validated.**

Section 6:

Discussion and conclusions

Chapter 12: Discussion

This thesis presents evidence-based consensus guidelines for the extrication of patients trapped following an MVC.

The principles of EBM have been utilised; we have reviewed the historic evidence base and provided supplementary relevant scientific evidence, we have ensured that patient values and preferences are heard and we have applied consensus finding techniques to utilise expert clinical judgement to produce the final guidance. Each Section of this thesis has considered a separate aspect of the EBM triad. Each Section concludes by summarising the new knowledge that has been generated and how this contributes to the aims and purpose of the thesis as a whole.

In this discussion we consider the implications for patients, the public, clinicians and rescue personnel. We discuss areas where there needs to be cautions in implementation, messaging and approach. Routes to successful dissemination and translation into practice are proposed. We finish with the international implications of this research and how it may be best adapted for international use.

Implications for patients

The implementation of this evidence-based guidance will promote a patient-centred approach to extrication. The focus on communication and building a connection with patients may lead to patients feeling better cared for, having a deeper understanding of the extrication plan and feeling engaged and empowered in minimising their entrapment time. Improved patient communication, engagement and understanding is associated with increased patient satisfaction and better outcomes across a wide variety of health care environments [328–330].

A reduced focus on absolute movement minimisation following an MVC will result in more self-extrication, a smaller number of trapped patients and a reduction in the incidence of tool-based extrication [4,173,243]. Clarity of messaging to the public will be needed both on when to self-extricate and how to remain safe post extrication; current guidance advises patients not to move if they are injured and to move out and away from their vehicle to minimise the risks of a secondary collision if they are not [331]. It is not yet clear if guidance to the public will change because of the work presented in this thesis. Options for implementing self-extrication include; empowering and equipping members of the public to make this decision themselves, enabling training for bystanders (see implications for the public section), supporting decision making around mobilisation and self-extrication via initial emergency call, training non-clinical responders such as police officers to assess patients suitability for self-extrication, enabling rescue services to make such decisions (as supported by the Delphi study reported in Chapter 10) or leaving this decision with clinicians. Each of the above scenarios will have its own implications for the training of professionals and education of the public. Each will lead to an impact on scene times for the uninjured, reduced accident-related traffic delays, a decrease in the tool-based destruction of vehicles from extrication, potentially improved patient outcomes and economic savings [332,333].

The extrication guidance produced as a result of this thesis is congruent with the literature related to other areas of prehospital and emergency practice and spinal injury. The guidance is supportive of gentle-patient handling over absolute movement minimisation and supports the concept that active patient-initiated movements such as self-extrication are associated with less overall movement and are therefore 'safer' than passive rescuer/clinician-initiated movements if a spinal cord injury is present [98,100,273,334,335]. Assuming this premise is correct and self-extrication is the safest route of egress for a vast majority, if not all, patients injured in an MVC who are physically capable of self-extrication then the harms of the widespread adoption of self-extrication will be minimal. There are potential unintended consequences including the risk of a secondary collision/injury and changes to triage status. The patient may be at increased risk after leaving their vehicle from a secondary collision compared to staying in their vehicle, analysis of guidance specific to this area presents variable data on the risk of this occurring, preventing us from accurately predicting the effect of increased extrication on secondary collision rates [331]. Current emergency service dispatch criteria prioritise patients who may be trapped and de-prioritise those who are not; as more patients self-extricate the average injury severity of this group will increase and the time to clinical attendance will rise (as a result of reduced priority dispatch) [336]. This divergence may result in a small number of patients who have successfully self-extricated but have time-dependent injuries having delayed access to clinical intervention and therefore poorer outcomes. Longitudinal analysis using resources such as the TARN dataset will enable the identification of such trends and dispatch criteria may need modification (see recommendations for further research).

A small number of patients identified pain as an important facet of their extrication experience (see Chapter 9). The combination of our new understanding of the injuries found in trapped patients (Chapters 3,4 & 5) and existing literature reporting a high prevalence of pain in the prehospital environment supports the conclusion that many injured patients who are trapped will have pain [211,243,259,337–339]. Meeting the pain needs of trapped injured patients whilst implementing and balancing the Delphi derived principles (Chapter 10) of minimising entrapment time and limiting clinical care to necessary critical interventions will require excellent on-scene communication, consideration of how analgesic needs are best met and a bespoke, patient centred analgesia plan [340]. Facilitating early access to analgesia will be important from both a humanitarian perspective (with access to pain management being an established human right) and in maximising the potential for patients to self-extricate whose movement may be limited by their pain [243,341]. Most patients with major trauma receive IV analgesia and establishing intravenous access is considered standard practice in the context of major trauma [342,343]. The need for IV access to facilitate analgesia presents challenges; the need for a clinician on scene, the time taken for the procedure itself and the intrinsic difficulty in achieving IV access in those patients that are hypovolaemic [344–346]. In addition, intravenously administered medications often require a minimum standard of physiological monitoring; the application and subsequent interaction by clinicians with this monitoring can lead to complexities in delivering the extrication itself and therefore prolong entrapment time [141,340]. Alternative routes of analgesia such as inhaled (e.g. methoxyflurane), intranasal (e.g. ketamine) or buccal (fentanyl lollipops / lozenges) which are used in other environments where IV access has similar challenges (such as in battlefield medicine) present useful alternatives [347–350]. In UK practice the clinical skill set of firefighters remains ill-defined with significant regional variations. Elsewhere in the world where rescue and clinical working practice are merged, or have more interoperability and shared capability, the challenge of the early administration of analgesia may be easier to meet [252,263].

Our patients in the qualitative interview work reported in Chapter 10 reported how they benefited from the presence of an extrication buddy. Extrication buddies were recommended by the SMEs engaged with the Delphi study reported in Chapter 11 [340]. Multidisciplinary discussion will help to determine whether this role is best provided by rescue services, clinical services or by both. This subject was discussed at a recent FPHC webinar in which the results of this thesis were presented; the expert panel and the audience were in favour of the extrication buddy role being delivered by rescue services [351]. Additional consideration should be given to the potential harms / benefits and mitigations (such as the provision of PPE) of supporting bystanders who have established a rapport with a patient in continuing this role once extrication has commenced. Many rescue services encourage a team member to join the patient in the vehicle to support them during entrapment. Traditionally this has been a role related to patient safety, the provision of instructions and PPE and has not had a particular focus on communication and psychological support [3]. Specific guidance and education on how to be an extrication buddy with regular review subject to longitudinal analysis of the patient experience will help to deliver improvements in this area of extrication practice.

Discouragement of onlooker and professional photography / videography and the use of social media may lead to reduced patient and relative distress both in the immediate phase of their injuries and during the subsequent recovery phase. Onlooker photography is common across accidents and medical events which occur outside of private environments, though the explanation for why the public so frequently photograph distressful events is unclear [319,320]. With the implementation of actions to reduce onlooker photography (such as legislation, signage or physical barriers) there may be a tension between encouraging bystanders to offer important, meaningful support to patients (such as contacting emergency services or companionship) and dissuading them from taking photographs or using social media in a way which is harmful or distressing [320]. More research is needed to understand the roles of bystanders at an MVC and how positive behaviours can be encouraged and negative behaviours discouraged; this is discussed in more detail in the 'Implications for the public" section of this discussion.

The avoidance of death and the preservation of health are of paramount importance to patients [352]. We have reported the injuries associated with entrapment and have demonstrated the excess mortality associated with this [211,243,259]. The adoption of the guidance developed in this thesis will lead to shorter entrapment times for the majority of patients. Patients with a shorter entrapment time should see their time to meaningful clinical intervention decrease, leading to a potential reduction in mortality [211]. The linkage, longitudinal analysis and reporting of routinely collected collision, rescue and trauma data will allow such a change in practice to be evidenced and any reduction in morbidity and mortality identified and reported.

Implications for the public

The guidance produced within this thesis will have implications for the public regarding initial actions on scene, contacting of and information communicated to the emergency services and potentially an enhanced role in providing psychological support to trapped patients.

In Chapter 9 we saw the positive effects of an extrication buddy for trapped patients; for the patients in the study this was on most occasions provided by a lay bystander. The purported “bystander effect” describes members of the public not assisting strangers in distress especially if other bystanders are present [353]. Public education campaigns and health care system changes have helped to overcome the bystander effect and encourage the public to perform cardiopulmonary resuscitation on pulseless collapsed patients [354,355]. The rate and quality of community delivered cardiopulmonary resuscitation (CPR) can be increased through EMS dispatcher delivered directions, simplification of messaging around actions, making training videos available in the public domain, maximising teaching time with mannequins and new technologies such as mobile device assisted quality feedback [354–356]. A similar bundle of multi-modal interventions including educational videos, “apps” to guide bystanders through initial on-scene actions, guidance to bystanders from EMS dispatchers and a training course for engaged lay people could be developed. These interventions could increase the rate and quality of psychological support for trapped patients, encourage bystanders to collect and report (verbally or with mobile phone based video assisted technology) on-scene and patient factors which will aid dispatch and perhaps enable initial bystander delivered care; such as attempts to control compressible haemorrage or CPR for impact brain apnoea [67,356,357]. The public are currently counselled not to move patients following an MVC so as not to exacerbate potential secondary spinal injury [331]. The guidance developed in this thesis may help this advice to be pragmatized; removing the ‘fear’ of causing harm to patients may enable bystander engagement with this patient group. Reducing such fears has had a positive effect on outcomes in other health care settings e.g. overcoming the fear in relation to medicolegal risk or patient exposure has helped improve bystander CPR rates [356]. In the future, increased availability of video, artificial intelligence (AI) and vehicle telemetry-based triage systems, supplemented by pragmatic bystander-delivered triage scoring systems may further enhance the fidelity of triage and increase the frequency and efficacy of bystander “buddy care” [127,310,312,358].

Implications for clinicians

Clinicians will need to work alongside rescue personnel and trapped patients to implement this guidance [340]. There may be patient ownership and boundary issues in relation to the in-vehicle delivery of time-critical and extrication enabling interventions as reported in other cross-specialty multidisciplinary ad hoc teams [359–361]**.** The solution to this will require enhanced on-scene and system-wide communication, joint training opportunities and increased co-operative working. Hospital trauma teams are similarly 'ad-hoc'; such teams see improvements in performance through the development of clear, replicable structures and roles (such as primary survey clinician or trauma team leader), defined workflows (primary survey and then CT scan) and both generic and specific situational communication skills training [360,361]**.** This learning could be transferred into standardised, multidisciplinary workflow and role development, with subsequent standardised training for extrication teams. Roles could include defined decision-making responsibilities (e.g. for in-vehicle clinical care), defined systems (e.g. attempt self-extrication first) and generic and specific communication training (such as how to communicate in-vehicle during tool use). Standardised communication structures and nomenclature are an important aspect of human-factors based performance and are evidenced to improve performance of ad-hoc teams, both in the setting of major trauma but also in other safety critical industries such as aviation [360–363]. The standardised nomenclature derived through the Delphi study presented in this thesis will facilitate communication in relation to scene and patient status [340]. Further work in this area would bring benefit through defining the timings and standardised structure of shared briefings to ensure efficient communication and transfer of critical information, perhaps utilising communication checklists or aide-memoires, which have shown benefit in other areas of multidisciplinary clinical practice [340,360,364].

Some clinicians will struggle to rely on clinical acumen and informed interpretation of vital signs for in-vehicle care, especially those with a low frequency of major trauma exposure (such is the case for many UK paramedics) [365]. Our Delphi derived principle of "all patients with evidence of injury should be considered time-dependent and their entrapment time should be minimised" will help towards standardisation of such care and a reduction in entrapment time regardless of clinician experience[340]. The adoption of this principle may be disproportionately beneficial to those with occult, time-dependent injuries; such patients are normally older or early in their clinical course and have a moderate to high ISS [366,367].

A core principle for extrication derived by this research is a primary focus on the minimisation of entrapment time [340]. Limiting in-car treatment to critical interventions as supported by our Delphi SME's will help to facilitate rapid extrication [141,340]. In the 'implications for patients' section of this discussion we discussed the challenges associated with IV access and the potential benefits of utilising alternative routes of administration of analgesia. Utilising the intramuscular (IM), intranasal, buccal or inhalational route for the administration of other time-critical medications (such as IM tranexamic acid (TXA)) may further reduce entrapment time whilst also benefiting the patient by decreasing time to the administration of these medications [368,369].

Entrapment and incident detail captured on initial call to emergency services and enhanced bystander engagement may lead to improved performance in triage and dispatch services [370]. Enabling patient-led self-extrication may lead to more patients self-identifying as uninjured and reduce the requirement for clinician attendance at MVCs and subsequent patient transfer to hospital leading to significant resource savings [371]. A 2014 study estimated the additional system costs of prehospital spinal immobilisation at $600 ($750 with inflation) per patient and FRS attendance is estimated to cost over £1000 per incident; across 2,500 extrications p.a. in the UK there is the potential for significant cost reduction [198,372].

Implications for rescue personnel

Rescue personnel will need to train for and deliver extrication care in closer partnership with their clinical colleagues. The guidelines developed here promote greater clinical autonomy for the FRS. There is significant variation nationally and internationally between the clinical capability and clinical governance structures of rescue services, this is particularly true in the UK as EMS and rescue personnel are only very rarely dual qualified and there is less service integration when compared to international practice [263,373,374]. FRS personnel are often on scene prior to clinicians and as they adopt clinical governance structures, increase their level of clinical training and move towards adopting the guidance derived in this thesis, firefighters may be enabled to deliver more potentially life-saving medications and interventions [368,374]. Increased clinical autonomy may lead to a general clinical upskilling of the FRS workforce, which may bring further benefit to patients through the early identification of pathology and the rapid delivery of clinical care. A potential detrimental effect may arise, particularly in any transition clinical phase where there may be a lack of clarity of skillset and role of the FRS in attending to patients; this has the potential to harm team performance which is considered in the 'implications for clinicians' section of this discussion [360].

UK FRS have agreed to adopt the principles for extrication outlined in this thesis and incorporate this guidance into their national operating guidance and supporting structures [252]. Successful adoption will require the enablement of clinical training and governance standards across the FRS sector which will have an associated resource and financial cost. The total cost will depend upon the chosen route for implementation and has not yet been estimated.

The implementation of the guidance developed here will lead to a lower number of entrapments where FRS attendance is required [173]. This decreased utilisation will allow the consolidation of resources and training to focus on incidents where disentanglement of patients is required [198]. This may reduce time to scene for such specialist resources and have a positive effect on further reduction of entrapment time.

The study presented in Chapter 8 demonstrates that all methods of extrication except for self-extrication result in similar patient movements [247]. A logical conclusion suggested by this finding and supported by the Delphi derived principles is that the rapid extrication methods associated with the shortest delivery (and as such entrapment) time should be more frequently utilised [247,340]. Rapid extrication methods require little or no cutting [3]. As the number of incidents where patients self-extricate or 'rapid' extrication techniques are utilised rise, patients requiring disentanglement (who all require a tool-based extrication) will rise as a proportion of total extrication experience. The decrease in the utilisation of cutting equipment may result in efficiency saving in terms of equipment purchasing and transport. However, a potentially negative consequence of this approach is that individual FRS personnel will have less opportunity to utilise their cutting equipment, gain extrication experience or apply rescue techniques and as a result their competence in delivering rescue may be adversely affected and this in turn may adversely affect patient outcomes [375]. The literature which describes the establishment of trauma systems and centralisation of trauma care outlines the problem of the maintenance of expertise in a low-utilisation environment well; with trauma centres demonstrating improved patient outcomes with increasing workload and smaller hospitals suffering from deskilled clinicians and unpractised systems [376,377]. A similar system which results in the regionalisation of extrication experience may need to occur to maintain this expertise; how such systems are established, funded, triaged and dispatched will need careful consideration [4,173,198].

Caution in messaging: gentle patient handling

The message of "gentle patient handling" needs to be clear in communications, education and training to all those involved in patient handling and rescue [340]. A key principle derived from this work is that absolute movement minimisation is an unjustified paradigm and small, considered movements are unlikely to cause additional harm to the very small number of patients that have unstable spine or cord injuries; patients will still need to be handled in a gentle and considerate manner [100,340]. We have demonstrated in Chapters 3,4 and 5 that many trapped patients suffer from abdominal and pelvic injuries; rough or inconsiderate handling may disrupt an established blood clot, cause pain and may lead to worse patient outcomes [211,259,378]. The patients interviewed about their experience in Chapter 10 reported the importance of considerate handling in ensuring a positive patient experience. This is a further reason to ensure that communication and education as these principles move into practice is clear and that quality assurance and clinical governance is robust.

Algorithms and complexity

Many aspects of prehospital triage and clinical decision making are captured in algorithmic guidance [379]. Such algorithms may be useful for training, standardisation of care and the reduction of bias in the delivery of healthcare [380]. However, extrications are complex and involve multiple factors such as environment, geography, the vehicles involved, energy transfer, patients, their specific injuries and available equipment and expertise [141]. Assessing and understanding these factors and their interactions will be challenging to capture in a traditional algorithm [380]. The adoption of a set of shared multidisciplinary principles as developed in this thesis with supporting education and enablement is likely to promote best practice and optimise patient outcomes in this complex environment [381]. This multidisciplinary education and enablement will be just one part of a wider collaborative framework of cooperation necessary to ensure optimum patient experience and outcomes.

Implications for future multidisciplinary research, collaboration, and perspective sharing

Considering MVC with entrapment is relatively common, the research available in relation to extrication is sparse (Chapter 2). Interdisciplinary research is challenging for practical, institutional and financial reasons; such potential obstacles are likely to be a contributing factor to the low numbers of research studies in this area [382]. Practical challenges to interdisciplinary research in this area include organising meetings and ensuring communication (perhaps now eased by the increased use of videoconferencing software brought about by the Covid-19 pandemic), developing a common language and ensuring a clear commonly held understanding of what the research needs to achieve. Financial and institutional obstacles are linked and include the considerations of funding secretariat, assigning costs /committing funds across organisations, research sponsor and governance hurdles, information governance and information sharing concerns and the consideration that most established research funding streams target single sector problems [383]. The 'blurred' patient ownership between rescue services (where little patient research occurs) and clinical services may further challenge research opportunity.

Previous research has demonstrated the value of shared terminology between disciplines to improve communication, interoperability and the quality of patient care. Shared nomenclature such as that developed in this thesis (e.g. 'casualties' now being referred to as 'patients') may help with improving shared values and ownership of shared challenges [384]. Other industries have struggled and overcome similar challenges; the traditionally hierarchical aviation industry has championed the widespread adoption of 'Crew Resource Management' (CRM) techniques and training which have led to improved safety [385,386]. These CRM principles have been widely adopted in other health care environments with positive results [362,387]. In the UK, Joint Emergency Services Interoperability Programme (JESIP) provides training to encourage emergency service interoperability; building on these principles with a multidisciplinary course dedicated to extrication based on CRM and the evidence-based extrication principles derived here may offer a solution to education in this multidisciplinary area [364]. Such a national level solution with a multidisciplinary steering group could offer standardisation of message, a central funding route, the resource to quality control and improve on the education developed and would benefit from the efficiencies of utilising an established multidisciplinary organisation. Countries and regions where JESIP or equivalents are not established could consider utilising established, alternative, multidisciplinary structures where they are available such as emergency preparedness, resilience and response groups.

The paradigm of absolute movement minimisation is without a justifiable evidence base; nonetheless it was historically 'championed' by a small number of influential clinicians who were associated with rescue services, EMS or had educational responsibilities [13,14]. The adoption of these principles has remained unchallenged for at least four decades, during which time the excess death associated with entrapment has not been investigated nor the paradigm reconsidered. If multidisciplinary clinical and operational governance structures were in place to allow such paradigms to be (re)considered, then change may have occurred sooner [388,389]. There are other areas of multidisciplinary practice between rescue and clinical services which would benefit from regular review and (re)consideration; where there is divergence in prioritisation between rescue and clinical strategies. Examples include the immediate treatment of burns, suspension trauma and crush injury [390–393]. Shared work and oversight will be especially important as the clinical and decision-making function of rescue services is enhanced and the need for multidisciplinary shared guidance is increased.

Translation into policy and practice

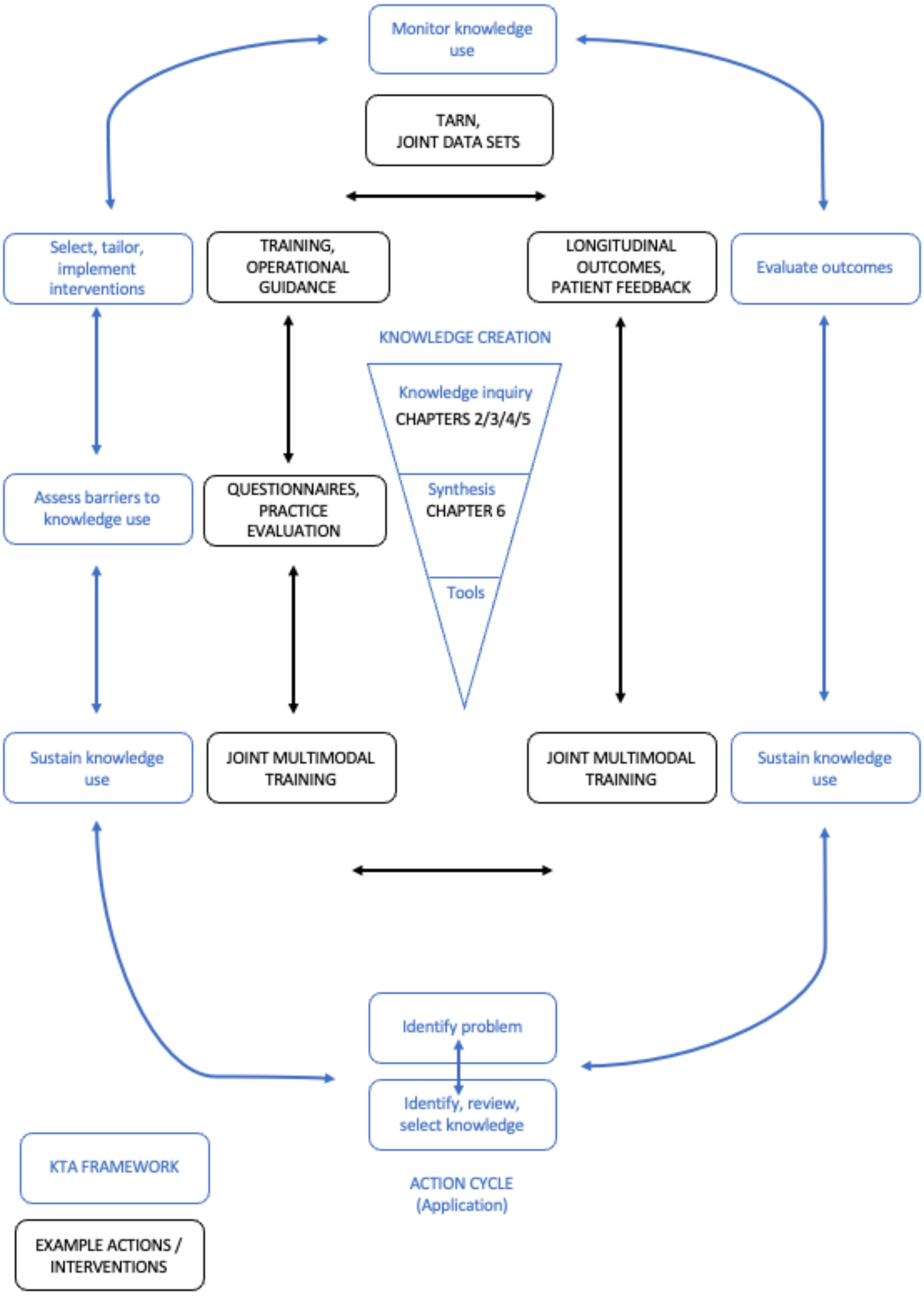
This thesis builds upon the work of multiple authors that have considered, reviewed and in some cases directly challenged prehospital immobilisation practice; including the 'immobilisation' which comes from absolute movement minimisation applied to extrication[95,98–100,179,180,182,275,279,394]. The challenge of overcoming established 'common' medical practice is a significant hurdle; a hurdle which delays the implementation of 'best practice', contributes to patient harm and necessitates the application of significant resource to achieve change [395–398]. A time lag of 17 years is often quoted for research evidence to translate effectively into clinical practice [398]. Where this timeline starts, (e.g. at point of ethics approval or publication) and finishes (e.g. translation into a clinical guideline or widespread adopted clinical practice) is reported variously throughout the literature preventing meaningful comparison between translation strategies [398]. A common key step in achieving effective translation is dissemination of research findings [399]. Suggested routes for dissemination include stakeholder summaries, the development of clinical guidance and engagement with clinicians and the public through the media (including social media); each of these methods will require translation of the findings for the intended audience. Examples of activities to facilitate dissemination of the results of this thesis can be found in Table 12.1 [399,400].

TABLE 12.1: ROUTES OF DISSEMINATION AND THIS THESIS (ADAPTED FROM CURTIS *ET AL*[400])

Suggested route of dissemination	Example of dissemination activity delivered or scheduled
Study site: summary results for stakeholders	Principles document agreed and reviewed by all contributory stakeholders [340]
Clinical and operational staff: present research findings at meetings and education sessions	Extrication, FPHC Webinar, UK, August 2022 Extrication, National Road Safety Forum, UK, August 2022 Extrication, The Resus Room Podcast, September 2022
Conference: choose best audience for the work	Extrication, RCEM Prehospital Care Study Day, September 2022 Extrication, London Trauma Conference, UK, December 2022 Prehospital spinal care and Extrication, Spinal Injuries Conference, UK, October 2022
Journal: Choose best audience for work, enable access	Journals chosen to maximise audience and accessibility based upon content of publication and target audience All journal publications open access to maximise accessibility
Social media: for example, Twitter	Use of social media to increase awareness High (top 1%) Altimetric scores for published papers [401]
Media: local newspaper, media release, hospital public relations, professional newsletter, or magazines	National media coverage [402–404]
Professional organisations	New national guidance in development with the NFCC, FPHC, COP.

There is an array of evidence-based models for the translation of research findings into practice [405,406]. The most relevant framework for a multidisciplinary intervention such as this new guidance is the Knowledge to Action (KTA) framework proposed by Graham and colleagues [407]. This framework consists of two interacting components: a knowledge creation funnel (which this thesis is a representative example of) and an action cycle (Figure 12.1).

FIGURE 12.1 KTA FRAMEWORK WITH EXAMPLE ACTIONS AND INTERVENTIONS (ADAPTED FROM GRAHAM *ET AL.* [407])



The key aspects identified by the KTA that will need to be considered in relation to this thesis and are important next steps to build on the dissemination work outlined above are:

- *Knowledge creation: the development of tools.* These tools will need to be discipline specific but feature shared nomenclature, priorities and targets based on the consensus document output of this thesis. These tools would be best formulated by a multidisciplinary group; perhaps drawn from the representative SMEs utilised in the Delphi study of this thesis (Chapter 6). These tools could be published through established routes such as the JRCALC guidance [379].

- *Action cycle: sustain knowledge use*. Knowledge will be shared through the tools discussed above. There will be a need for multidisciplinary training to ensure that knowledge is shared and the new approaches trusted. Multidisciplinary extrication and patient training should routinely feature in initial training schemes (e.g. paramedic university curricula) and mandatory updates.
- *Action cycle: assessing barriers to knowledge use*. Surveys, feedback from training delivered and ongoing governance of extrication cases will enable the identification of challenges to knowledge application.

  The un-learning of decades of established practice will be a huge challenge[408]. As well as providing specific and high-quality educational interventions, specific wiping or directed un-learning interventions will need to occur, such interventions may include culture change in relation to extrication approach, a practice-based approach using scenarios or root-cause analysis type reviews [409].
- *Action cycle: select, tailor, implement interventions.* Interventions include the tools, training, mentorship and case review highlighted above. Additional interventions will be informed by the repeated application of the KTA action cycle. In the future, joint AI driven 'apps' may offer bespoke training and on-scene guidance.
- *Action cycle: monitor knowledge use.* The application of these guidelines can be assessed using case review, patient reported outcome measures and routine reporting of clinical and extrication interventions. These would benefit from standardisation across prehospital clinical and FRS providers. Current routinely collected data reports patient, clinical and injury details separately to extrication and accident-related details [198]. Linking these datasets for longitudinal analysis will allow an enhanced understanding and identification of trends, monitoring of extrication practices and entrapment times and an understanding of patient injures and outcomes.
- *Action cycle: evaluate outcomes.* Longitudinal analysis of patient outcomes and extrication types will be an essential aspect of translation to practice. In the UK, the TARN dataset could be augmented to include details of vehicle type, extrication route, type and entrapment time or the national FRS dataset

could be linked by case to TARN. Routine analysis could report adjusted mortality, rate of unstable spinal injury and morbidity and mortality in a similar way to the papers presented in Section 2.

Translation to other areas of rescue and prehospital practice

Clinical practice is moving away from routine immobilisation as the evidence base for interventions such as the application of a cervical collar are increasingly challenged [98–100]. This thesis contributes novelty not only by providing evidence, but also by outlining a methodological approach that can be followed for other prehospital and rescue environments. This includes both the application of the EBM structure to these 'shared' environments and more specifically by considering the incidence of unstable injuries and other time dependent injuries, performing situation specific biomechanical analysis, capturing the patient perspective and using SMEs to help translate findings into guidance.

It is likely that many aspects of the guidance derived within this thesis are applicable to other rescue situations where patient movement needs to occur or be facilitated. With appropriate consideration, patient and expert input this guidance could be translated for people trapped in other situations, such as following a natural disaster / building collapse or injured whilst caving or climbing. As well as complex extrication scenarios, these principles could be adopted for more routine prehospital situations where patients are currently not encouraged to mobilise or are routinely handled with movement minimisation techniques, such as an older patient falling on their residential stairs or a fall outside.

Translation to non-UK environments

This research was conducted in the UK. The SMEs used in the final stage of the guidelines all work in UK clinical and operational practice. Steps were taken to ensure translation into other geographic regions e.g., the analysis of chain cabling extrication, which is not delivered in UK practice. These guidelines will translate effectively into rescue and healthcare settings with a similar structure and training to the UK, which is likely to include most higher income countries (HIC).

Translation in Low- and Middle-Income Countries

This guidance has been produced utilising personnel and stakeholders based in a HIC. However, 93% of fatal accidents and serious injury occur in LMICs as such, translation of these finding for LMIC practice offers huge potential for improving patient experience and outcomes [1,410].

The literature reports a number of barriers to the effective translation of clinical guidance from HICs to LMICs. Barriers reported in the literature include: the quality of the guidance itself, the guidance's applicability to patients within LMICs and ensuring the guidance is contextualised and adapted to the resource and staffing availability of LMIC settings [411,412].

We have established the quality of this evidence-based guidance through the application of EBM principles and the process of producing this thesis itself. There will be a benefit of repeating the studies presented in Chapters 3,4 and 5 which report injuries and outcomes associated with entrapment utilising data collected in LMICs. MVC related injury patterns in LMICs may differ from that seen in HIC due to differences in driving habits, the proportion of cars with modern safety systems on the road and compliance with such systems (e.g. seatbelt wearing is close to 100% in HICs and approximately 50% in LMICs) [50,56,146,228,259,413–416]. Current unknowns which would benefit from further research are understanding the rate of spinal injury in the injured population in the region for which the guidance is being developed, the rate of other time dependent injuries and the region-specific excess mortality associated with entrapment. Repeating the qualitative interview study described in Chapter 10 would ensure local cultural perspectives are captured. Finally, local SMEs from operational and clinical practice should be found to translate available evidence into guidance. The studies described in this paragraph would help to ensure both that the developed guidance was applicable to patients within LMICs but also that the local context, health and operational infrastructure were considered.

The physical costs (a potential resource challenge) of implementing this guidance beyond translation and education are minimal as implementation does not require physical or capital resource; this may overcome potential resource hurdles in the practical application of the guidance into LMICs when compared to other new clinical practices which may come with significant resource implications (e.g. the purchase of MRI scanners). Costs of the implementation of the guidance could be further reduced by the suggested centralisation of extrication expertise being accompanied by the centralisation of expensive extrication tools, resulting in less overall cost to purchase, maintain and transport such equipment.

The combination of careful review, additional evidence collection, local adaptation and translation will all support effective translation of the evidence-based guidance derived here for LMICs.

Limitations

There are limitations to the individual studies which make up this thesis; these are discussed within the individual chapters and section review.

The guidelines that result from this thesis will require further translation into tools to enable their adoption and engagement, legislation changes to enable some aspects of their enactment and longitudinal analysis to monitor impact and patient outcomes.

The guidance produced in this thesis will be a challenge to translate into traditional algorithmic guidelines. If such algorithmic guidance is required (e.g. for specific professions or those with infrequent clinical and operational experience) then this will require further consensus work.

A key aspect where additional research and guidance is required is the extrication of patients with physical entrapment who require tool extrication. This is a complex matter and biomechanical data for such patients will be challenging to acquire in sufficient numbers to be meaningful. The rationalisation of FRS resource in dealing with those without physical entrapment will generate time and resource for those with such entrapment. The principles of analysis, multidisciplinary consensus and critical thinking will ensure that these interventions are considered, critically evaluated, refined, and optimised.

Recommendations for further research

A recommendation of this thesis is the formation of a multidisciplinary dataset that will allow longitudinal analysis of extrication practices and patient outcomes. Such analysis should become routine and reported in the public domain.

Consideration should be given to the development of methods which can be applied by lay persons, allied professionals (such as the police) or by FRS at the scene of a collision to ensure an appropriate operational and clinical response to a trapped patient. The application of such methods will enable the equitable and optimal distribution of extrication and clinical resources. The utilisation of these resources may also enable the delivery of certain medications and / or interventions (such as IM TXA). As data becomes available in relation to the effects of implementing this guidance on the time to treatment for injured patients who self-extricate, consideration will need to be given to adapting current dispatch guidance which prioritises trapped patients over those who are able to mobilise to ensure optimal clinical care.

Specific attention should be given to the development of guidance for the physically trapped patient. The findings of this research will be useful as a basis for a reconsideration of approach in this area.

The established regional organisation and delivery of clinical and operational care in the UK may enable efficiencies in utilising (stepped-wedge) cluster randomised controlled trial methodology which is useful for assessing the effect of change in service-delivery or policy implementation [417]. Established regions could be randomised to implementation of the new guidance or maintain current standard practice. Using routinely collected data (such as TARN) to describe trial outcomes would offer efficiencies of data-collection and reporting compared to more traditional trial methodologies which use dedicated resource to collect trial specific data. Randomised controlled trials which demonstrate important differences in an unambiguous, patient centred outcome such as death are most likely to influence the adoption of guidance [418]. If randomised controlled trials in relation to this guidance are considered unnecessary or face funding / delivery challenges, it may be that a "natural experiment" provides the necessary evidence for consideration / adoption. Natural experiments are most utilised in the public-health literature and involve monitoring differences between different policies and interventions in either a before and after comparison or between different geographic regions [419]. Such an experiment could monitor differences between regions which adopt the guidance suggested here and those that do not. Such an experiment would review relevant, routinely reported data to demonstrate if correlation exists between adoption and outcomes across a range of endpoints of interest (such as deaths associated with MVCs).

A further area in which consensus still needs to be reached relates to the use of collars as an extrication device. A large pragmatic randomised trial of collar use in trauma is planned in the UK (SIS – spinal immobilisation study) which may offer direction in this area [420].

The principles of extrication outlined in this thesis should be adapted for and then tested in LMICs.

Chapter 13: Conclusions

The principles of EBM have been used to provide new evidence base guidance for the extrication of patients who are trapped following an MVC.

In Section 1 a scoping review of the literature identifies that current extrication practices and paradigms are not grounded in evidence and that references to a high rate of spinal injuries caused by rescuer handling are 'zombie' statistics without an identifiable origin. Section 1 highlights unknowns including: the rate of spinal injuries and time dependent injuries in the trapped population, the excess morbidity and mortality associated with entrapment across a range of patient groups, the spinal movements associated with current extrication techniques and an understanding of the patient experience of extrication.

In Section 2, three retrospective cohort studies found that trapped patients have more injuries and are more likely to die; the rate of spinal injuries that are likely to influence extrication technique is extremely low; there are differences in the entrapment rates and injury patterns between female and male patients; older people have an excess mortality associated with entrapment and have a similar potential for self-extrication as younger people [211,243,259].

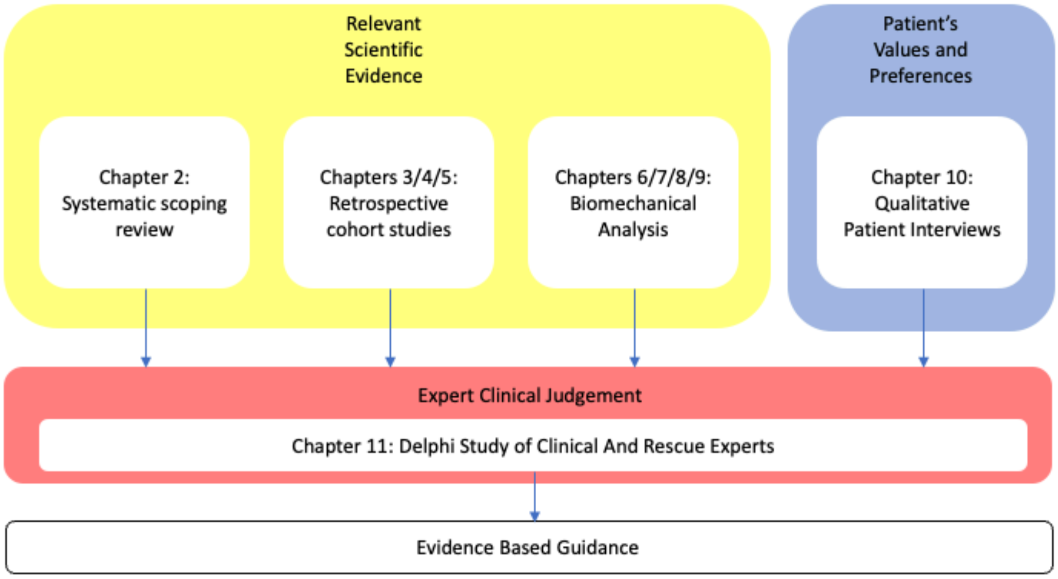
In Section 3, four original papers report the movements associated with current extrication techniques. These papers identify that self-extrication is associated with smaller movements at the cervical and lumbar spine than other extrication types and that extrication types that are not self-extrication appear to be similar in movement generation at the cervical and lumbar spine [247,281,286].

Section 4 focuses on patient values and preferences. A single study reports a series of qualitative patient interviews. The experience of entrapped patients was improved by positive communication, companionship, explanations and planned post-incident follow-up. The experience of entrapped patients was made worse by communication failures, loss of autonomy, unmanaged pain, poor communication with remote family and the negative effects of onlooker use of social media.

In Section 5, a Delphi consensus study, used SMEs to formulate extrication guidance based on the evidence made available in Sections 1-4 of this thesis. The synthesis of these statements in collaboration with national level stakeholders into new principles will have significant implications for clinicians, rescuers, and patients.

This guidance has been adopted by a broad range of national level clinical and rescue stakeholders [340].

FIGURE 13.1 EVIDENCE BASED MEDICINE AND STUDIES CONTRIBUTING TO THIS RESEARCH



We have demonstrated that the historic paradigm of 'movement minimisation' in the development and application of extrication techniques is not grounded in evidence and that such an approach may contribute to the excess death associated with entrapment.

An evidence-based approach to extrication is proposed; this approach is validated through its adoption by national level stakeholders in the UK. Such an approach will reduce extrication times and may reduce morbidity and mortality. The impact following the adoption of the principles resulting from this thesis on extrication type, time and patient outcomes will be monitored through longitudinal analysis of national level data sets.

END

Tim Nutbeam, August 2022

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Appendices:

1) Ethical Approvals
2) Semi-structured Patient Survey
3) List of Abbreviations

Appendix 1: Ethical Approvals

UNIVERSITY OF CAPE TOWN
Faculty of Health Sciences
Human Research Ethics Committee

Room G50- Old Main Building
Groote Schuur Hospital
Observatory 7925
Telephone [021] 406 6492
Email: hrec-submissions@uct.ac.za
Website: www.health.uct.ac.za/fhs/research/humanethics/forms

29 June 2021

HREC REF: 180/2021

Dr W Stassen
Division of Emergency Medicine
F-51, OMB
Email: willem.stassen@uct.ac.za
Student: timnutbeam@nhs.net

Dear Dr Stassen

PROJECT TITLE: TO DESCRIBE THE INJURY PATTERNS, MORBIDITY AND MORTALITY OF PATIENTS INVOLVED IN MVCS (TRAPPED AND NOT TRAPPED) (STUDY 1) (PHD DEGREE – DR TIM NUTBEAM)

Thank you for your response letter addressing the issues raised by the Faculty of Health Sciences Human Research Ethics Committee.

It is a pleasure to inform you that the HREC has **formally approved** the above-mentioned study, subject to local approvals.

This approval is subject to strict adherence to the HREC recommendations regarding research involving human participants during COVID -19, dated 17 March 2020 & 06 July 2020.

Approval is granted for one year until the 30 June 2022.

Please submit a progress form, using the standardised Annual Report Form if the study continues beyond the approval period. Please submit a Standard Closure form if the study is completed within the approval period.
(Forms can be found on our website: www.health.uct.ac.za/fhs/research/humanethics/forms)

The HREC acknowledge that the student: - Dr Tim Nutbeam will also be involved in this study.

Please quote the HREC REF 180/2021 in all your correspondence.

Please note that the ongoing ethical conduct of the study remains the responsibility of the principal investigator.

Please note that for all studies approved by the HREC, the principal investigator **must** obtain appropriate institutional approval, where necessary, before the research may occur.

HREC/REF 180/2021sa

Yours sincerely

PROFESSOR M BLOCKMAN
CHAIRPERSON, FACULTY OF HEALTH SCIENCES HUMAN RESEARCH ETHICS COMMITTEE
Federal Wide Assurance Number: FWA00001637.
Institutional Review Board (IRB) number: IRB00001938
NHREC-registration number: REC-210208-007

This serves to confirm that the University of Cape Town Human Research Ethics Committee complies to the Ethics Standards for Clinical Research with a new drug in patients, based on the Medical Research Council (MRC-SA), Food and Drug Administration (FDA-USA), International Council for Harmonisation of Technical Requirements for Pharmaceuticals for Human Use: Good Clinical Practice (ICH GCP), South African Good Clinical Practice Guidelines (DoH 2020), based on the Association of the British Pharmaceutical Industry Guidelines (ABPI), and Declaration of Helsinki (2013) guidelines. The Human Research Ethics Committee granting this approval is in compliance with the ICH Harmonised Tripartite Guidelines E6: Note for Guidance on Good Clinical Practice (CPMP/ICH/135/95) and FDA Code Federal Regulation Part 50, 56 and 312.

UNIVERSITY OF CAPE TOWN
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30 August 2021

HREC REF: 529/2021

Dr W Stassen
Division of Emergency Medicine
F-51 OMB
Email: willem.stassen@uct.ac.za
Student: timnutbeam@nhs.net

Dear Dr Stassen

PROJECT TITLE: THE ROLE OF CERVICAL COLLARS AND VERBAL INSTRUCTIONS IN MINIMISING SPINAL MOVEMENT DURING SELF-EXTRICATION FOLLOWING A MOTOR VEHICLE COLLISION-PHD CANDIDATE-DR TIM NUTBEAM-STUDY 2

Thank you for submitting your study to the Faculty of Health Sciences Human Research Ethics Committee (HREC) for review.

It is a pleasure to inform you that the HREC has **formally approved** the above-mentioned study.

Please note that data cannot be destroyed in June 2021, as per the informed consent document, please update.

This approval is subject to strict adherence to the HREC recommendations regarding research involving human participants during COVID -19, dated 17 March 2020; 06 July 2020 & 01 July 2021.

Approval is granted for one year until the 30 August 2022.

Please submit a progress form, using the standardised Annual Report Form if the study continues beyond the approval period. Please submit a Standard Closure form if the study is completed within the approval period.
(Forms can be found on our website: www.health.uct.ac.za/fhs/research/humanethics/forms)

The HREC acknowledge that the student: Dr Tim Nutbeam will also be involved in this study.

Please quote the HREC REF 529/2021 in all your correspondence.

Please note that the ongoing ethical conduct of the study remains the responsibility of the principal investigator.

Please note that for all studies approved by the HREC, the principal investigator **must** obtain appropriate institutional approval, where necessary, before the research may occur.

HREC/REF 529/2021sa

Yours sincerely

PROFESSOR M BLOCKMAN
CHAIRPERSON, FACULTY OF HEALTH SCIENCES HUMAN RESEARCH ETHICS COMMITTEE
Federal Wide Assurance Number: FWA00001637.
Institutional Review Board (IRB) number: IRB00001938
NHREC-registration number: REC-210208-007

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30 August 2021

HREC REF: 530/2021

Dr W Stassen
Division of Emergency Medicine
F-51 OMB
Email: willem.stassen@uct.ac.za
Student: timnutbeam@nhs.net

Dear Dr Stassen

PROJECT TITLE: STUDY 3: BIOMECHANICAL ANALYSIS OF RAPID AND CONTROLLED EXTRICATION (STUDY 3)-PHD CANDIDATE DR TIM NUTBEAM

Thank you for submitting your study to the Faculty of Health Sciences Human Research Ethics Committee (HREC) for review.

It is a pleasure to inform you that the HREC has **formally approved** the above-mentioned study.

Please note that data cannot be destroyed in June 2021, as per the informed consent document, please update.

This approval is subject to strict adherence to the HREC recommendations regarding research involving human participants during COVID -19, dated 17 March 2020; 06 July 2020 & 01 July 2021.

Approval is granted for one year until the 30 August 2022.

Please submit a progress form, using the standardised Annual Report Form if the study continues beyond the approval period. Please submit a Standard Closure form if the study is completed within the approval period.
(Forms can be found on our website: www.health.uct.ac.za/fhs/research/humanethics/forms)

The HREC acknowledge that the student: Dr Tim Nutbeam will also be involved in this study.

Please quote the HREC REF 530/2021 in all your correspondence.

Please note that the ongoing ethical conduct of the study remains the responsibility of the principal investigator.

Please note that for all studies approved by the HREC, the principal investigator **must** obtain appropriate institutional approval, where necessary, before the research may occur.

HREC/REF 530/2021sa

Yours sincerely

PROFESSOR M BLOCKMAN
CHAIRPERSON, FACULTY OF HEALTH SCIENCES HUMAN RESEARCH ETHICS COMMITTEE
Federal Wide Assurance Number: FWA00001637.
Institutional Review Board (IRB) number: IRB00001938
NHREC-registration number: REC-210208-007

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30 August 2021

HREC REF: 531/2021

Dr W Stassen
Division of Emergency Medicine
F-51 OMB
Email: willem.stassen@uct.ac.za
Student: timnutbeam@nhs.net

Dear Dr Stassen

PROJECT TITLE: BIOMECHANICAL ANALYSIS OF CHAIN CABLING EXTRICATION (STUDY 4)-PHD CANDIDATE-DR TIM NUTBEAM

Thank you for submitting your study to the Faculty of Health Sciences Human Research Ethics Committee (HREC) for review.

It is a pleasure to inform you that the HREC has **formally approved** the above-mentioned study.

This approval is subject to strict adherence to the HREC recommendations regarding research involving human participants during COVID -19, dated 17 March 2020; 06 July 2020 & 01 July 2021.

Approval is granted for one year until the 30 August 2022.

Please submit a progress form, using the standardised Annual Report Form if the study continues beyond the approval period. Please submit a Standard Closure form if the study is completed within the approval period.
(Forms can be found on our website: www.health.uct.ac.za/fhs/research/humanethics/forms)

The HREC acknowledge that the student: Dr Tim Nutbeam will also be involved in this study.

Please quote the HREC REF 531/2021 in all your correspondence.

Please note that the ongoing ethical conduct of the study remains the responsibility of the principal investigator.

Please note that for all studies approved by the HREC, the principal investigator **must** obtain appropriate institutional approval, where necessary, before the research may occur.

Yours sincerely

PROFESSOR M BLOCKMAN
CHAIRPERSON, FACULTY OF HEALTH SCIENCES HUMAN RESEARCH ETHICS COMMITTEE

HREC/REF 531/2021sa

Federal Wide Assurance Number: FWA00001637.
Institutional Review Board (IRB) number: IRB00001938
NHREC-registration number: REC-210208-007

This serves to confirm that the University of Cape Town Human Research Ethics Committee complies to the Ethics Standards for Clinical Research with a new drug in patients, based on the Medical Research Council (MRC-SA), Food and Drug Administration (FDA-USA), International Council for Harmonisation of Technical Requirements for Pharmaceuticals for Human Use: Good Clinical Practice (ICH GCP), South African Good Clinical Practice Guidelines (DoH 2006), based on the Association of the British Pharmaceutical Industry Guidelines (ABPI), and Declaration of Helsinki (2013) guidelines. The Human Research Ethics Committee granting this approval is in compliance with the ICH Harmonised Tripartite Guidelines E6: Note for Guidance on Good Clinical Practice (CPMP/ICH/135/95) and FDA Code Federal Regulation Part 50, 56 and 312.

Project [P100527]

Biomechanical analysis of Scandinavian methods for vehicular passenger extraction.

Project Details | Comments (4) | Downloads | Approval Steps

Project Information	
Project ref	**P100527**
Full name	James Shippen
Faculty	[URC] University Research Centre
School/FRC	[FT] Institute for Future Transport and Cities
Module Code	FTC-STAFF
Project Title	Biomechanical analysis of Scandinavian methods for vehicular passenger extraction.
Project Dates	01/03/2020 - 31/12/2020
Date Created	21/01/2020 14:28
Project Summary	*This study will use two fire engine fitted with chains to reverse the deformity of a car involved in a front-end collision and will record the movement of a healthy volunteer who will be inside the car during the study.* *This method of extrication is used in a number of European countries and is considered the 'gold standard' method in Scandinavian countries – as such it is widely used and is known to be safe and effective.* *Despite this method is widely used across many EU countries following collisions little is known with regard to the movement caused to the person inside of the car.* *The car will be prepared using cuts along the roof by competent firefighters using approved equipment and methods, chains will then be fitted. At this point the volunteer subject will enter the vehicle and a highly controlled exercise will be performed using the winch to 'stretch' the car and allow access to the volunteer.* *The healthy volunteer will wear Fire Service PPE (personal protective equipment), helmet, gloves and eye protection together with Xsens IMU sensors. The study will be supervised by both Fire Service instructors and medical professionals. During the study the directi*
Names of Co-Investigators (CIs) and their organisational affilation (place of study/employer):	*James Shippen, Coventry University* *Barbara May, Coventry University* *Mike Dayson, National Fire Chiefs Council* *Tim Nutbeam, Devon Air Ambulance* *Rob Fenwick, West Midlands NHS*

UNIVERSITY OF CAPE TOWN
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17 August 2021

HREC REF: 182/2021

Dr W Stassen
Division of Emergency Medicine
F-51 OMB
Email: willem.stassen@uct.ac.za
Student: timnutbeam@nhs.net

Dear Dr Stassen

PROJECT TITLE: A QUALITATIVE STUDY OF PATIENT EXPERIENCE OF EXTRICATION – STUDY 5 (PHD DEGREE – DR TIM NUTBEAM)

Thank you for your response letter, addressing the issues raised by the Faculty of Health Sciences Human Research Ethics Committee (HREC).

It is a pleasure to inform you that the HREC has **formally approved** the above-mentioned study.

This approval is subject to strict adherence to the HREC recommendations regarding research involving human participants during COVID -19, dated 17 March 2020; 06 July 2020 & 01 July 2021.

Approval is granted for one year until the 30 August 2022.

Please submit a progress form, using the standardised Annual Report Form if the study continues beyond the approval period. Please submit a Standard Closure form if the study is completed within the approval period.
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The HREC acknowledge that the student: Dr Tim Nutbeam will also be involved in this study.

Please quote the HREC REF 182/2021 in all your correspondence.

Please note that the ongoing ethical conduct of the study remains the responsibility of the principal investigator.

Please note that for all studies approved by the HREC, the principal investigator **must** obtain appropriate institutional approval, where necessary, before the research may occur.

Yours sincerely

PROFESSOR M BLOCKMAN
CHAIRPERSON, FACULTY OF HEALTH SCIENCES HUMAN RESEARCH ETHICS COMMITTEE

HREC/REF 182/2021sa

Federal Wide Assurance Number: FWA00001637.
Institutional Review Board (IRB) number: IRB00001938
NHREC-registration number: REC-210208-007

This serves to confirm that the University of Cape Town Human Research Ethics Committee complies to the Ethics Standards for Clinical Research with a new drug in patients, based on the Medical Research Council (MRC-SA), Food and Drug Administration (FDA-USA), International Council for Harmonisation of Technical Requirements for Pharmaceuticals for Human Use: Good Clinical Practice (ICH GCP), South African Good Clinical Practice Guidelines (DoH 2006), based on the Association of the British Pharmaceutical Industry Guidelines (ABPI), and Declaration of Helsinki (2013) guidelines. The Human Research Ethics Committee granting this approval is in compliance with the ICH Harmonised Tripartite Guidelines E6: Note for Guidance on Good Clinical Practice (CPMP/ICH/135/95) and FDA Code Federal Regulation Part 50, 56 and 312.

UNIVERSITY OF PLYMOUTH

29th January 2021

Dr Tim Nutbeam
School of Health Professions
Faculty of Health
University of Plymouth
The Emergency Department
Derriford Hospital
Plymouth PL6 8DH

Dear Tim

Amendment of Approval by Faculty Research Ethics and Integrity Committee

Reference Number: **19/20-1288**
Application Title: **Understanding people's experiences of extrication whilst being trapped in motor vehicles following a collision: a qualitative study.**

The Chair has given ethical approval for your minor amendment to the application originally approved on 20th October 2020.

This approval is until 19th October 2022, after which you will be required to seek extension of existing approval. Please note that if you wish to make any MAJOR changes to your research you must inform the Committee. Please contact the Faculty Research Administrator, Maurice Bottomley (email FOHsethics@plymouth.ac.uk).

Yours sincerely

Professor Sarah Neill,
PhD, PGD Res. Deg. Sup., PGDE, MSc, BSc(Hons), RGN, RSCN, RNT
Professor of Nursing
Co-Chair, Research Ethics and Integrity Committee - Faculty of Health

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UNIVERSITY OF CAPE TOWN
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Website: www.health.uct.ac.za/fhs/research/humanethics/forms

13 July 2021

HREC REF: 183/2021

Dr W Stassen
Division of Emergency Medicine
F-51 OMB
Email: willem.stassen@uct.ac.za
Student: timnutbeam@nhs.net

Dear Dr Stassen

PROJECT TITLE: DEVELOPING NEW GUIDANCE ON EXTRICATION USING DELPHI METHODOLOGY –STUDY 6 (PHD DEGREE – DR TIM NUTBEAM)

Thank you for your response letter, addressing the issues raised by the Faculty of Health Sciences Human Research Ethics Committee.

It is a pleasure to inform you that the HREC has **formally approved** the above-mentioned study.

This approval is subject to strict adherence to the HREC recommendations regarding research involving human participants during COVID -19, dated 17 March 2020 & 06 July 2020.

Approval is granted for one year until the 30 July 2022.

Please submit a progress form, using the standardised Annual Report Form if the study continues beyond the approval period. Please submit a Standard Closure form if the study is completed within the approval period.
(Forms can be found on our website: www.health.uct.ac.za/fhs/research/humanethics/forms)

The HREC acknowledge that the student: Dr Tim Nutbeam will also be involved in this study.

Please quote the HREC REF 183/2021 in all your correspondence.

Please note that the ongoing ethical conduct of the study remains the responsibility of the principal investigator.

Please note that for all studies approved by the HREC, the principal investigator **must** obtain appropriate institutional approval, where necessary, before the research may occur.

Yours sincerely

PROFESSOR M BLOCKMAN
CHAIRPERSON, FACULTY OF HEALTH SCIENCES HUMAN RESEARCH ETHICS COMMITTEE

HREC/REF183.2021sa

Federal Wide Assurance Number: FWA00001637.
Institutional Review Board (IRB) number: IRB00001938
NHREC-registration number: REC-210208-007

This serves to confirm that the University of Cape Town Human Research Ethics Committee complies to the Ethics Standards for Clinical Research with a new drug in patients, based on the Medical Research Council (MRC-SA), Food and Drug Administration (FDA-USA), International Council for Harmonisation of Technical Requirements for Pharmaceuticals for Human Use: Good Clinical Practice (ICH GCP), South African Good Clinical Practice Guidelines (DoH 2020), based on the Association of the British Pharmaceutical Industry Guidelines (ABPI), and Declaration of Helsinki (2013) guidelines. The Human Research Ethics Committee granting this approval is in compliance with the ICH Harmonised Tripartite Guidelines E6: Note for Guidance on Good Clinical Practice (CPMP/ICH/135/95) and FDA Code Federal Regulation Part 50, 56 and 312.

21st October 2020

Dr Tim Nutbeam
School of Health Professions
Faculty of Health
University of Plymouth
The Emergency Department
Derriford Hospital
Plymouth PL6 8DH

Dear Tim

Application for Approval by Faculty Research Ethics and Integrity Committee

Reference Number: **19/20-1313**
Application Title: **Developing new evidence-based guidance for the extrication of patients trapped in motor vehicles following a collision using Delphi methodology.**

The Chair has granted ethical approval to conduct this research.

Please note that this approval is for 12 months (until 20th October 2021), after which you will be required to seek extension of existing approval.

Please note that if you wish to make any MAJOR changes to your research you must inform the Committee. Please contact the Faculty Research Administrator, Maurice Bottomley (email FOHsethics@plymouth.ac.uk).

Yours sincerely

Professor Sarah Neill,
PhD, PGD Res. Deg. Sup., PGDE, MSc, BSc(Hons), RGN, RSCN, RNT
Professor of Nursing
Co-Chair, Research Ethics and Integrity Committee - Faculty of Health

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Appendix 2: Semi-structured interview guide (Chapter 5):

1): Please tell me about your extrication experience

How did you get out of the vehicle? (self, bystander, emergency services, cutting equipment used)

What was this like? Physically and emotionally

Was there anyone else in the car with you?

How were they throughout?

2: Can you tell me about what you were feeling whilst you were trapped in your vehicle?

What were the physical feelings?

Did you have injuries?

What thoughts and feelings came to mind? About your-self and others?

3: Can you tell me what you felt your immediate needs were when you were still inside your vehicle, and were these met?

Were you in pain? Were you given pain relief?

Was anyone talking to you throughout? What was that like?

Did you feel reassured? Was there compassion / care?

Did you require assistance in leaving the vehicle, how did this go?

4: Thinking back, could your extrication experience have been better or worse?

Pain and temperature?

Explanations, compassion / care?

Assistance in leaving the vehicle

Communication, physical handling, e.g. pain of equipment / boards etc

Time taken?

Anything else?

5): We believe that a long extrication may lead to higher rates of injury and death. Could your extrication have been speeded up and still met your needs?

Could you have self-extricated, or left the vehicle with a small amount of assistance?

<u>Prompts for all questions can include:</u>

Extrication type

Patient experience:

noise

pain

temperature

concern for injuries and other family members

How treated by rescuers:

Communication

Physical handling

Pain of equipment / boards etc

Time taken:

Actual time and experience of this time

Actions within the vehicle:

Needs addressed (pain / warmth / understanding / communication)

Appendix 3: List of Abbreviations:

AAOS	American Academy of Orthopaedic Surgeons
AI	Artificial Intelligence
AIS	Abbreviated Injury Score
AP	Anteroposterior
ATLS	Advanced Trauma Life Support
BMI	Body Mass Index
CI	Confidence Interval
CORDEQ	COnsolidated criteria for REporting Qualitative research
CREDES	Conducting and Reporting Delphi Studies
CRM	Crew Resource Management
EBM	Evidence Based Medicine
ED	Emergency Department
EJ	Ejection
EMS	Emergency Medical Services
EThOs	E-theses Online service
EX	Extrication
FPHC	Faculty of Prehospital Care

FRS	Fire and Rescue Services
GCS	Glasgow Coma Scale
HEMS	Helicopter Emergency Medical Service
HIC	Higher Income Country
HMIC	Healthcare Management Information Consortium
IM	Intramuscular
IMU	Inertial Measurement Unit
IQR	Interquartile Range
ISS	Injury Severity Score
IV	Intravenous
JESIP	Joint Emergency Services Interoperability Programme
KED	Kendrick Extrication Device
KTA	Knowledge to Action
LAT	Lateral
LMIC	Lower- and Middle-Income Country
LR	Lateral
LSB	Long Spinal Board
MCID	Minimally Clinical Important Difference

MILNS	Manual In-Line Neck Stabilisation
MOI	Mechanism of Injury
MRI	Magnetic Resonance Imaging
MVA	Motor Vehicle Accident
MVC	Motor Vehicle Collision
NDLTD	Networked Digital Library of Theses and Dissertation
NFCC	National Fire Chiefs Council
NHRAF	National HEMS Research & Audit Forum
NHS	National Health Service
OATD	Open Access Theses and Dissertations
OF	Occupant Fatality
OR	Odds Ratio
PHOTON	Pre-Hospital Trainee Operated Research Network
PPE	Personal Protective Equipment
PPV	Positive Predictive Value
PRISMA-ScR	Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews
PSI	Passenger Space Intrusion

PTSD	Post-Traumatic Stress Disorder
RTC	Road Traffic Collision
SGBA	Sex and gender-based analysis
SME	Subject Matter Expert
STD DEV	Standard Deviation
TARN	Trauma Audit Research Network
TXA	Tranexamic Acid
UK	United Kingdom
UKRO	United Kingdom Rescue Organisation
UN	United Nations
US	United States
WHO	World Health Organisation
Ws	W statistic