

Biomechanical analysis of spinal immobilisation during prehospital extrication: a proof of concept study

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ABSTRACT

Background In most countries, road traffic collisions (RTCs) are the main cause of cervical spine injuries.

There are several techniques in use for spinal immobilisation during prehospital extrication; however, the evidence for these is currently poor.

Objective The objective of this study is to establish which technique provides the minimal deviation of the cervical spine from the neutral inline position during the extrication of the RTC patient using biomechanical analysis techniques.

Methods A crew of two paramedics and four firefighter first responders extricated a simulated patient from a prepared motor vehicle using nine different extrication techniques. The patient was marked with biomechanical sensors and relative movement between the sensors was captured via high speed infrared motion analysis cameras. A 3D mathematical model was developed from the recorded movement.

Results Control measurements were taken from the patient during self-extrication and movement was recorded of 4.194° left of midline (LOM) to 2.408° right of midline (ROM) resulting in a total movement of 6.602°. The least deviation recorded during equipment aided extrication was movement of 3.365° LOM and 8.352° ROM resulting in a total movement of 11.717°. The most deviation recorded during equipment aided extrication was movement of 1.588° LOM and 24.498° ROM resulting in a total movement of 26.086°.

Conclusions Conventional extrication techniques record up to four times more cervical spine movement during extrication than controlled self-extrication. This proof of concept study demonstrates the need for further evaluation of current rescue techniques and the requirement to investigate the clinical and operational significance of such movement.

INTRODUCTION

Cervical spine injuries are devastating events that can lead to paralysis, disability, decreased quality of life and significant medical costs. It has been estimated that up to 20 000 cases of spinal cord injuries occur annually in Northern Europe and the USA.¹ In most countries, road traffic collisions (RTCs) are the main cause of cervical spine injuries.²

The emergency services use a variety of techniques to enable prehospital extrication of an entrapped patient from an RTC and these have previously been well described.³ Rapid extrications are implemented when a time-critical patient is haemodynamically unstable, because it is difficult to administer acute care inside a crashed vehicle and

entrapment delays transport to definitive care.⁴ Controlled extrications are applied to stabilised casualties with non-life threatening primary injuries where the mechanism of injury dictates a high index of suspicion for cervical spine injury. A potential cause of secondary injury is through inadvertent manipulation of the spinal cord during extrication.⁵ It has previously been reported that up to 25% of cervical cord trauma occurs because of improper immobilisation after the initial accident and therefore may be preventable.⁶

The current evidence base for spinal immobilisation techniques during prehospital extrication is poor. It appears that traditional prehospital extrication techniques have evolved through pragmatism rather than being introduced following rigorous evidence-based scientific research. Therefore, the aim of this study is to establish which technique provides the minimal deviation of the cervical spine from the neutral inline position during the controlled extrication of the RTC patient using biomechanical analysis techniques.

METHODS

Setting and participants

The study was conducted in accordance with the Declaration of Helsinki and was approved by the Scientific Research Ethics Committee of the Mid-Western Regional Hospital, Limerick, Ireland. The location of the study was Limerick Corporation Fire and Rescue Station. A simulated crash vehicle (Mazda 323, Mazda Motor Corporation, Hiroshima, Japan) was prepared prior to initiation of the study with standard rescue cuts through A, B and C posts and subsequent roof and seat-belt pre-tensioner removal. Airbag safety was ensured through disconnection of the vehicle's electrical system. Scene safety was paramount and all necessary safety precautions including vehicle stabilisation, sharp covers (Holmatro UK, Nottingham, UK) and standard glass management protocols were in place within the vehicle itself and in the surrounding area. The extrication crew consisted of four members of the Fire Service in addition to two members of the National Ambulance Service totalling a crew of six members. This represents standard deployment levels for RTC attendance in the study region. All members of the crew were fully trained in manual handling and lifting techniques with previous experience of extrication and equipment such as the long spinal board (LSB) (Hi-Tech 2001, Dixie USA Inc, Texas, USA) and short extrication jacket (SEJ) (Kendrick Extrication Device, Ferno, West Yorkshire, UK). A healthy



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volunteer acted as the patient during the simulated extrications. The volunteer was a member of the National Ambulance Service and therefore was familiar with extrication procedures. Written informed consent was obtained from a male volunteer (height 180 cm and weight 80 kg) who was randomly selected from a pool of National Ambulance Service volunteers.

Biomechanical analysis

The movements of the volunteer were captured using 3D motion analysis cameras (Cortex, Motion Analysis Corporation, California, USA). Reflective markers were placed on the volunteer in a horizontal plane at the level of the zygoma and in a parallel horizontal plane consistent with the anatomical marking of the clavicles (figure 1). Reflective markers were also placed in a single vertical alignment along the anterior midline from the frontal bone to the xiphoid process. Infrared cameras (n=11) sampling at 200 Hz were set up and calibrated (to an accuracy of 0.1 mm) around the vehicle (figure 2). The cameras recorded the movement of the markers in 3D space. Following data capture, biomechanical analysis of the movement of the markers in all three planes was conducted. The movements in these planes are combined to produce an absolute angle of movement reflecting combined anterior–posterior, medial–lateral and rotational movement of the head relative to the torso throughout the extrication process (figure 1).

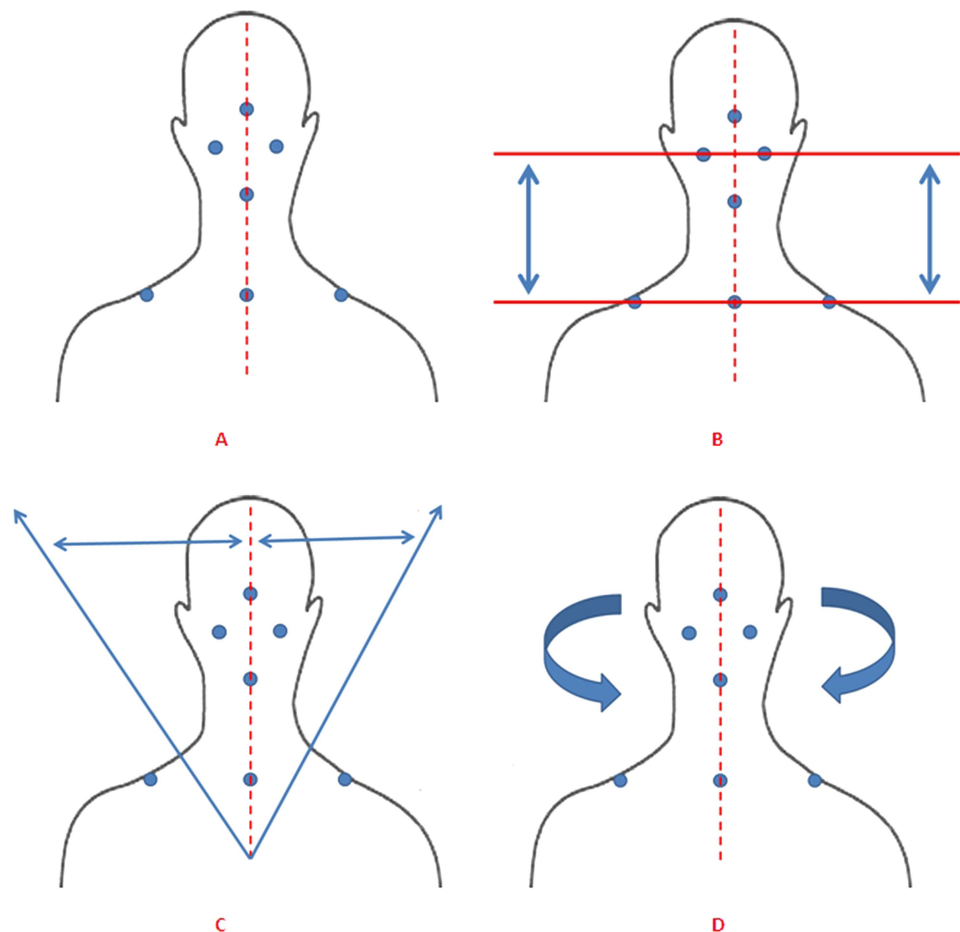
Protocol for immobilisation and extrication techniques

The controlled immobilisation and extrication techniques were randomised on the day of the study. For clarity, the techniques were then numbered in a logical order as presented here. Each

technique was performed once by the extrication crew and the starting point for all techniques was with the volunteer sitting in the driver seat of the test vehicle wearing a cervical collar (Stifneck, Laerdal Medical, Stavanger, Norway).

1. The volunteer exits the vehicle under his own volition while following careful instructions from paramedics regarding his movements (Control) (see table 1 for self-extrication instructions).
2. The volunteer exits the vehicle under his own volition with manual c-spine stabilisation while following careful instructions from paramedics regarding his movements (Control + manual support). This extrication technique while not documented in standard extrication techniques appeared worthy of consideration and was adopted at the request of the rescuers involved in the study.
3. The volunteer is removed using the ‘parcel shelf’ technique which consists of an inline extrication through the rear window using an LSB (LSB inline).
4. The volunteer is immobilised using the SEJ and removed using an inline extrication through the rear window with the SEJ secured to the LSB (SEJ inline). This technique is not currently specified by the manufacturers of the SEJ; however, consensus among national ambulance and fire/rescue training schools in Ireland confirmed this as a valid operational method. It should be noted that once the patient is positioned onto the LSB, the SEJ crotch straps are released.
5. The volunteer is assisted with a 90° rotation to the door side, a LSB is inserted behind the volunteer at an angle and the crew slides the volunteer up the board. The volunteer is then extricated head first through the passenger door (LSB passenger).

Figure 1 (A) Location of reflective markers. (B) Sagittal plane movement. (C) Frontal plane movement. (D) Transverse plane movement.



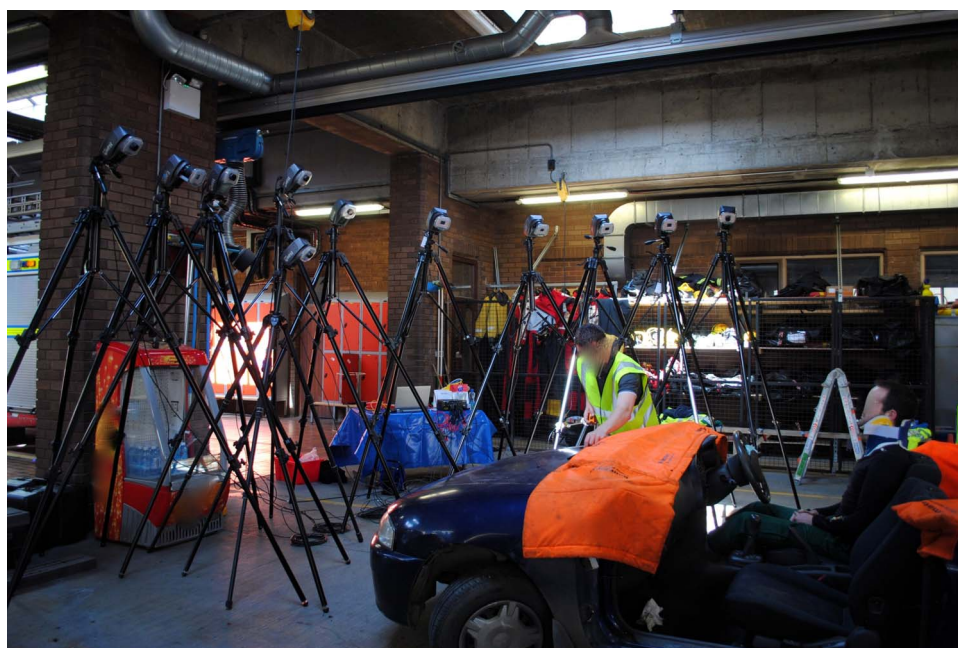


Figure 2 Set up of vehicle and cameras for the extrication scenarios.

6. The volunteer is immobilised using the SEJ, then assisted with a 90° rotation to the passenger side and removed through the passenger door (SEJ passenger).
7. The volunteer is assisted with a 90° rotation to the passenger side, an LSB is inserted behind the volunteer at an angle and the crew slides the volunteer up the board. The volunteer is then extricated head first through the driver door (LSB driver).
8. The volunteer is immobilised using the SEJ then assisted with a 90° rotation to the door side and removed through the driver door (SEJ driver).
9. The volunteer is immobilised using the SEJ and lifted through the driver door without rotation (SEJ driver-R).

Data analysis

Data were entered into an Excel spreadsheet (Microsoft, San Diego, California, USA) for analysis and descriptive statistics included calculation of means, SDs and ranges.

Table 1 Self-extrication instructions

Instruction sequence	Instruction
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

RESULTS

Control measurements were taken from the patient during self-extrication under verbal instruction and movement was recorded of 4.194° left of midline (LOM) to 2.408° right of midline (ROM) resulting in a total movement of 6.602°. In comparison, the least deviation recorded during equipment aided extrication (SEJ driver-R) was movement of 3.365° LOM and 8.352° ROM resulting in a total movement of 11.717°. The most deviation recorded during equipment aided extrication (SEJ inline) was movement of 1.588° LOM and 24.498° ROM resulting in a total movement of 26.086°. Data for all extrication techniques are illustrated in figure 3 with further details outlined in table 2.

DISCUSSION

Few acute treatments for spinal injuries have been subjected to controlled clinical trials and the emergency care of patients who may have spinal injuries has become highly ritualised.⁷ This proof of concept study set out to begin establishing an evidence

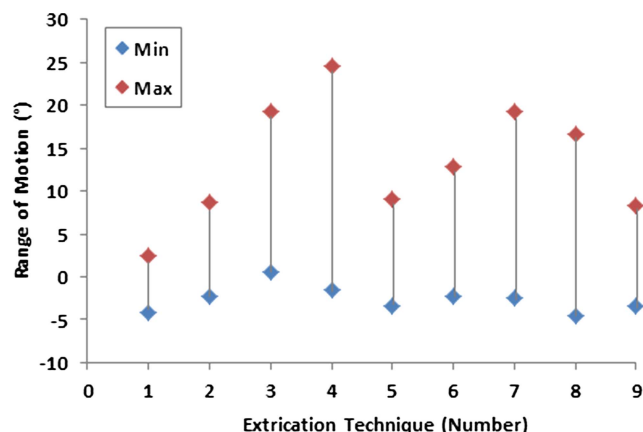


Figure 3 Minimum and maximum values and range of motion (°) for extrication techniques.

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Table 2 Biomechanical measurements (°) for extrication techniques

	Control	Control+manual support	LSB inline	SEJ inline	LSB passenger	SEJ passenger	LSB driver	SEJ driver	SEJ driver (-R)
No.	1	2	3	4	5	6	7	8	9
Average	-0.189	0.292	9.849	3.836	0.187	0.646	0.842	0.461	0.568
SD	1.025	1.905	3.313	3.453	1.308	2.525	2.631	3.279	1.190
Min	-4.194	-2.225	0.620	-1.588	-3.460	-2.192	-2.470	-4.546	-3.365
Max	2.408	8.775	19.358	24.498	9.013	12.870	19.197	16.683	8.352
Range	6.602	11.000	19.978	26.086	12.473	15.062	21.667	21.229	11.717

LSB, long spinal board; SEJ, short extrication jacket.

base for several of the techniques which are currently in use for spinal immobilisation during prehospital extrication. In this study, controlled self-extrication resulted in a total movement of 6.602° from the neutral inline position of the cervical spine. In comparison, the most deviation recorded during equipment aided extrication (SEJ inline) was a total movement of 26.086°. These results suggest that standard extrication techniques can record up to four times more cervical spine movement during extrication than controlled self-extrication.

These findings are in agreement with recently published work by Engsborg *et al.*⁸ In this study, the authors evaluated four common extrication techniques using a two person extrication crew in a mock vehicle. It was found that the two assisted protected techniques used (cervical collar+backboard and cervical collar+SEJ) did not offer the same level of protection as when the driver exited the vehicle unassisted with just cervical collar protection. During the recline-on-board experimental event there was significantly greater range of motion for the SEJ technique compared with the cervical collar unassisted technique for both lateral flexion ($p=0.010$) and rotation ($p=0.048$).⁸ However, one limitation of this analysis is that the seat backs of the mock vehicle used in the study were replaced with Plexiglas which would reduce friction during extrication and therefore may have implications for real world findings.

It appears that progress is now being made in establishing a scientific evidence base for spinal immobilisation techniques used during prehospital extrication. However, the clinical significance of the cervical spine movement that occurs during extrication is yet to be fully determined. A normal sagittal cervical spinal canal has been reported to have a diameter of 13–15 mm.⁹ In a simulated rear automobile crash using a model with no head restraint, peak narrowing of the canal was 1.8 mm at C5/6 and of the foramen 1.9 mm in width, 3.9 mm in height and 6.5 mm² in area at C4/5.¹⁰ The results of that study demonstrated foraminal kinematics sufficient to compress spinal ganglia and nerve roots. Of course energy depositions during extrication and emergency care are orders of magnitude less than that of the primary or secondary impacts⁷ but this should be further investigated in order to determine its true clinical significance for RTC patients.

Conservative treatment of suspected spinal injuries and overtriage by prehospital practitioners occurs because of the severe consequences of cervical spine injuries. However, the potential for adverse clinical effects and discomfort from immobilisation have been well documented.^{11–13} Unnecessary immobilisation due to overtriage also places an increased burden on ambulance services and overcrowded emergency departments. Based on the preliminary results reported here the modification of clinical practice guidelines in relation to cervical spine immobilisation during extrication cannot be recommended at this stage. It is

unclear as yet how transferable these findings are to the real world due to the inherent limitations of performing this type of research in a laboratory setting with a subject who is familiar with immobilisation and extrication techniques. However, this study does add to the growing body of evidence suggesting that current rescue techniques may not be providing optimal care for the post-RTC patient.

This is a proof of concept study and therefore is limited by its small sample size meaning that statistical significance could not be calculated. Future work should be sufficiently powered and include more detailed biomechanical analysis (including calculation of Euler angles) across variable patient groups.

CONCLUSIONS

Standard extrication techniques record up to four times more cervical spine movement during extrication than controlled self-extrication. This proof of concept study demonstrates the need for further evaluation of current rescue techniques and the requirement to investigate the clinical significance of cervical spine movement during extrication.

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Contributors All of the authors were involved in the design of the study. JOH conducted the biomechanical analysis. NC and MD drafted the manuscript and all authors reviewed the draft and approved the final submitted version.

Competing interests None.

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Data sharing statement Additional unpublished data from the study is currently available to the authors only.

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