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Confirmation of suboptimal protocols in spinal immobilisation?

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ABSTRACT**Background** Spinal immobilisation during extrication of patients in road traffic collisions is routinely used despite the lack of evidence for this practice. In a previous proof of concept study (n=1), we recorded up to four times more cervical spine movement during extrication using conventional techniques than self-controlled extrication.**Objective** The objective of this study was to establish, using biomechanical analysis which technique provides the minimal deviation of the cervical spine from the neutral in-line position during extrication from a vehicle in a larger sample of variable age, height and mass.**Methods** A crew of two paramedics and four fire-fighters extricated 16 immobilised participants from a vehicle using six techniques for each participant.

Participants were marked with biomechanical sensors and relative movement between the sensors was captured via high-speed infrared motion analysis cameras. A three-dimensional mathematical model was developed and a repeated-measures analysis of variance was used to compare movement across extrication techniques.

Results Controlled self-extrication without a collar resulted in a mean movement of 13.33° from the neutral in-line position of the cervical spine compared to a mean movement of 18.84° during one of the equipment-aided extrications. Two equipment-aided techniques had significantly higher movement (p<0.05) than other techniques. Both height (p=0.003) and mass (p=0.02) of the participants were significant independent predictors of movement.**Conclusions** These data support the findings of the proof of concept study, for haemodynamically stable patients controlled self-extrication causes less movement of the cervical spine than extrications performed using traditional prehospital rescue equipment.**INTRODUCTION**

In most countries road traffic collisions (RTC) are the main cause of cervical spine injuries.¹ Since the 1960s it has been standard practice to immobilise patients with suspected spinal injuries using a cervical collar and backboard.² Spinal immobilisation is based on the premise that minimising movement can reduce the risk of secondary neurological injuries occurring if the patient has sustained an unstable spinal fracture. However, the current evidence base for spinal immobilisation techniques during prehospital extrication is poor. In a Cochrane systematic review of the literature on spinal immobilisation of trauma patients, no randomised controlled trials (RCT) met the inclusion

Key messages**What is already known on this subject?**

- ▶ In most countries road traffic collisions 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.
- ▶ In a previous proof of concept study (n=1), we recorded up to four times more cervical spine movement during extrication using conventional techniques than self-controlled extrication.

What might this study add?

- ▶ In a larger sample size of haemodynamically stable patients, controlled self-extrication caused less movement of the cervical spine than extrications performed using traditional emergency medical services rescue equipment.
- ▶ These results add to the growing body of evidence suggesting that current rescue techniques may not be providing optimal care for post-road traffic collisions patients.

criteria for the review.³ The authors of this study concluded that the effect of spinal immobilisation on mortality, neurological injury, spinal stability and adverse effects in trauma patients remains uncertain.

It appears that traditional prehospital extrication techniques used by the emergency medical services (EMS) have evolved through pragmatism rather than being introduced following evidence-based scientific research. Conservative treatment of suspected spinal injuries and overtriage by prehospital practitioners occurs because of the severe consequences of spinal cord injuries (SCI).⁴ However, the potential for adverse clinical effects and discomfort as a result of immobilisation has been well documented.⁵⁻⁷ Unnecessary immobilisation due to overtriage also places an increased burden on ambulance services and emergency departments.

Recently, the emergency medicine community has started critically examining the rationale for routine immobilisation of trauma patients.⁸⁻¹¹ A proof-of-concept study undertaken by the authors demonstrated that up to four times more cervical spine movement occurs when traditional EMS rescue equipment (rigid collar, long spinal board (LSB) and short extrication jacket (SEJ)) is used in

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comparison to haemodynamically stable patients self-extricating under paramedic instructions.¹² The primary aim of this study was to build on these findings by increasing the sample size and including a range of male and female participants of variable age, height and mass to represent the general adult population of potential RTC patients.

METHODS

Study design

Ethical approval for this cross-sectional study was obtained from the Scientific Research Ethics Committee at the University Hospital Limerick. A power calculation was not possible as there are no previous studies with sufficient data to estimate variability in cervical spine movement between participants. A sample size of 15 participants was considered adequate to estimate variability.¹³ The most important consideration is that the participants are representative of the general adult population in order to ensure that study findings are potentially transferable to the real-world setting.

Setting and participants

The study location was Limerick City Fire and Rescue Station. Volunteers were recruited from the University of Limerick campus community via email and were divided into three mass categories: <65, 65–80 and >80 kg. Exclusion criteria included age <18 years, prior knowledge of extrication procedures and underlying medical conditions which may be affected by the extrication, including but not limited to arthritis, degenerative spinal conditions, previous back or neck injuries and pregnancy. On arrival at the Fire Station, the participants were briefed on the study and received a video induction. Participants were then provided with a study information sheet and written informed consent was obtained. Height and mass were measured on calibrated instruments.

Extrication crew and equipment

The crew for each extrication 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 this region. For health and safety reasons and to avoid repetitive strain injury, a pool of six fire personnel and three paramedics were available for the study and rotated between extrications to allow for adequate rest periods. All members of the crew were fully trained in manual handling and lifting techniques with previous experience of extrication and equipment such as the cervical collar (Stifneck, Laerdal Medical, Stavanger, Norway), LSB (Hi-Tech 2001, Dixie USA, Texas, USA) and SEJ (Kendrick Extrication Device, Ferno, West Yorkshire, UK).

Extrication vehicle

A test vehicle (Ford Focus, Ford Motor Company, Michigan, USA) was prepared prior to initiation of the study with standard rescue cuts through A, B and C posts and subsequent roof and seat-belt pretensioner removal. The test vehicle had all glass replaced with Perspex and sharp edges were ground and body-shop finished to ensure participant safety. The vehicle was also modified so that the roof assembly, A, B and C posts can be safely removed and subsequently reassembled via locating pins attached to the removed sections. Airbag safety was ensured through removal of the vehicle's electrical system. Scene safety was paramount and all necessary precautions including

vehicle stabilisation and standard Fire Service Safety Procedures were in place within the vehicle itself and in the surrounding areas.

Biomechanical analysis

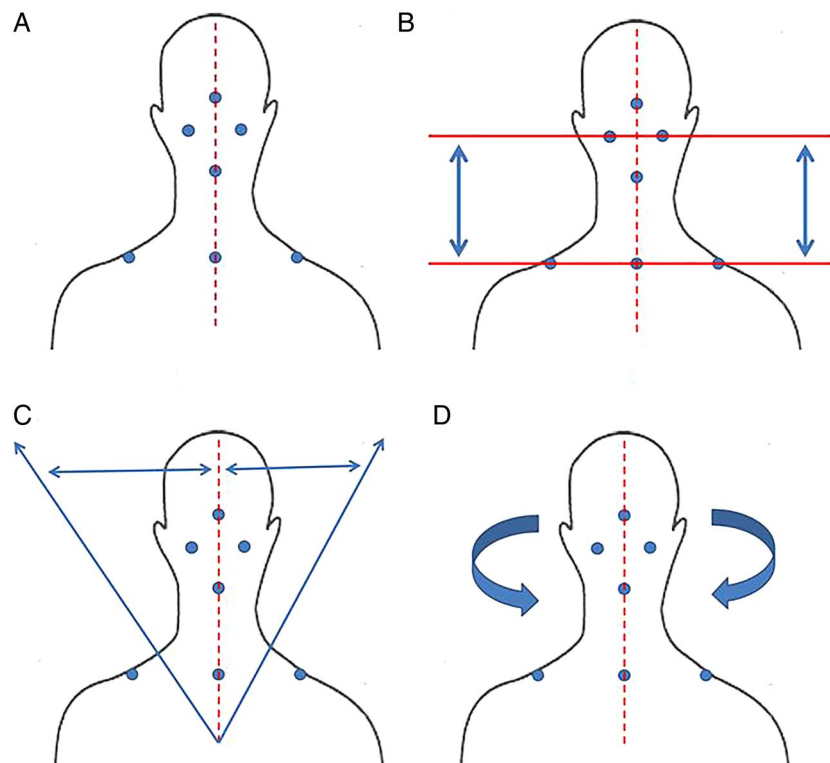
Reflective markers were placed on the participants in a horizontal plane at the level of the zygoma and in a parallel horizontal plane consistent with the anatomical marking of the clavicles. Reflective markers were also placed in a single vertical alignment along the anterior midline from the frontal bone to the xiphoid process (figure 1A). Narrowing of the horizontal planes represents flexion of the cervical spine and widening of the horizontal planes represents extension of the cervical spine (figure 1B). Lateral movement deviating to the left and right of the midline represents lateral movement of the cervical spine (figure 1C). Transverse left or right movement around the midline axis represents rotation of the cervical spine (figure 1D). The movements of the participants were captured using three-dimensional (3D) motion analysis cameras (Cortex, Motion Analysis Corporation, California, USA). Infrared cameras (n=12) 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.

Protocol for immobilisation and extrication techniques

The order of the immobilisation and extrication techniques was randomised for each participant using a random number generator. For clarity, the techniques were then numbered in a logical order as presented here and each technique was performed once by the extrication crew for each participant. The starting point for all techniques was with the participant sitting in the driver seat of the test vehicle facing straight ahead.

1. The participant exits the vehicle under his or her own volition while following careful instructions from paramedics regarding their movements (control—no collar). Self-extrication instructions are outlined in table 1.
2. The participant is fitted with a cervical collar and exits the vehicle under his or her own volition with manual c-spine stabilisation while following careful instructions from paramedics regarding their movements (collar+manual support).
3. The participant is fitted with a cervical collar and is removed using the 'parcel shelf' technique which consists of in-line extrication through the rear window using an LSB (LSB in-line).
4. The participant is fitted with a cervical collar and is assisted with a 90° rotation to the door side; an LSB is inserted behind the participant at an angle and the crew slides the participant up the board. The participant is then extricated head first through the passenger door (LSB passenger).
5. The participant is fitted with a cervical collar and is assisted with a 90° rotation to the passenger side; an LSB is inserted behind the participant at an angle and the crew slides the participant up the board. The participant is then extricated head first through the driver door (LSB driver).
6. The participant is fitted with a cervical collar and is immobilised using the SEJ and lifted through the driver door without rotation (SEJ driver).

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



Data analysis

Numerical data were exported from the Cortex software into a spreadsheet (Microsoft Excel, San Diego, California, USA) and tested for normality in SPSS (V21 Microsoft, California, USA). Numerical summaries (mean, SD and range) are presented. Pearson's correlation coefficient was used to measure the strength of the correlation between height, mass and movement for each extrication technique. A repeated-measures analysis of variance with extrication technique as the repeated measure and including height or mass as covariates was used to compare movement across techniques. Multiple pairwise comparisons with a Bonferroni correction were used to identify which techniques had significantly different movement. The software packages Excel and SPSS were used for data analysis.

RESULTS

Participant characteristics

A total of 16 participants enrolled in the study (seven males and nine females) with a mean age of 24 years (range 18–40 years). Mean height was 174 cm (range 157–198 cm) and mean mass was 76 kg (range 50–138 kg). There were five participants with mass <65 kg, six in the 65–80 kg mass category and five with mass >80 kg.

Biomechanical data

Control measurements were taken from the participants during self-extrication under verbal instruction with no collar and the mean cervical spine movement for all participants was 13.33°

Figure 2 Setup of vehicle and cameras for the extrication scenarios.



Table 1 Paramedic verbal instructions for participant self-extrication

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.

$\pm 2.67^\circ$ (table 2) and ranged from 8.25° to 18.79° . Measurements were also taken from the participants during self-extrication under verbal instruction with a collar fitted and manual support resulting in a mean movement of $14.93^\circ \pm 1.51^\circ$ with a range of 12.36° to 17.57° . In comparison, the smallest mean cervical spine movement recorded during equipment-aided extrication (LSB in-line) was movement of $13.56^\circ \pm 2.34^\circ$ and ranged from 9.40° to 17.25° . The largest mean cervical spine movement recorded during equipment-aided extrication (LSB driver) was $18.84^\circ \pm 3.46^\circ$ with a range of 13.25° to 26.89° . Mean movement for all participants during the SEJ extrication was $17.60^\circ \pm 3.15^\circ$ and ranged from 13.25° to 22.60° (figure 3). Mean movement was significantly different across extrication techniques ($p < 0.001$) with the mean movement recorded for LSB driver and SEJ driver techniques significantly higher ($p < 0.05$) than the movement recorded for the following four techniques:

- ▶ control (no collar)
- ▶ collar (manual support)
- ▶ LSB (in-line)
- ▶ LSB (passenger).

Influence of anthropometric measurements on extrication

The correlation of mass and height with cervical spine movement was calculated for each extrication technique (table 3). The strongest correlation between cervical spine movement and mass is for LSB (passenger) with a tendency for heavier individuals to experience more movement. Over 37% of the variability in movement was explained by mass of the participant for this extrication technique. Mass is an independent predictor of movement ($p = 0.02$) in a repeated measures model which includes technique as a factor.

The strongest correlation between cervical spine movement and height is for SEJ driver with a tendency for taller individuals to experience more movement (table 3). Over 42% of the variability in movement is explained by height of the participant for this extrication technique. The correlation between cervical spine movement and height is also strong for control (no collar; table 3). Height is an independent predictor of movement ($p = 0.003$) in a repeated measures model which includes technique as a factor.

DISCUSSION

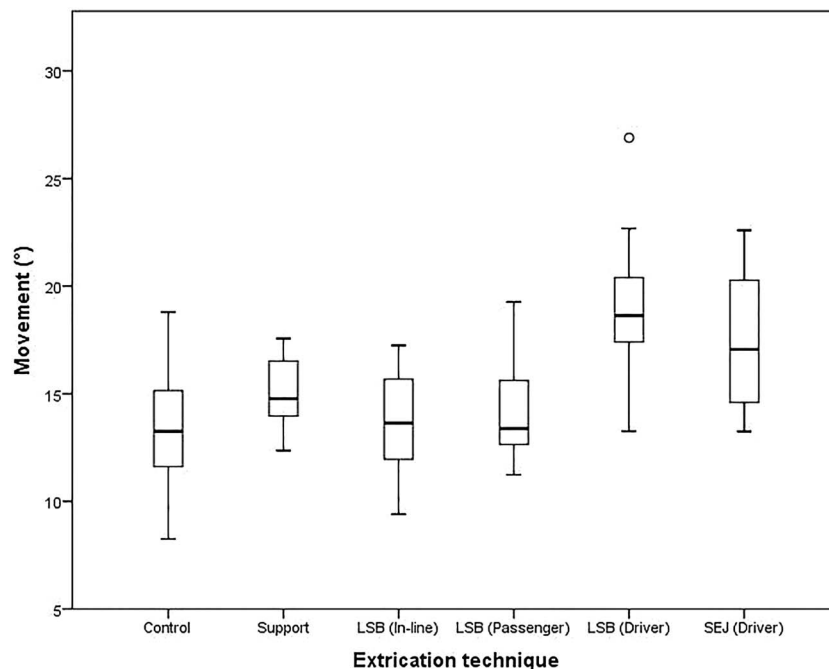
To date, the emergency care of trauma patients with suspected spinal injuries has been highly ritualised; however, progress is now being made in establishing a scientific evidence base for spinal immobilisation techniques used during prehospital extrication. In this study, controlled self-extrication without a cervical collar resulted in a mean movement of $13.33^\circ \pm 2.67^\circ$ from the neutral in-line position of the cervical spine. In comparison, the most deviation recorded during equipment-aided extrication (LSB driver) was a mean movement of $18.84^\circ \pm 3.46^\circ$. The LSB driver and SEJ driver techniques resulted in significantly more movement of the cervical spine during extrication than the other techniques evaluated in this study ($p < 0.05$).

Table 2 Biomechanical measurements ($^\circ$) for extrication techniques

Subjects	Control (no collar)	Collar (support)	LSB (in-line)	LSB (passenger)	LSB (driver)	SEJ (driver)
1	10.54	14.17	15.74	12.64	18.94	22.60
2	11.25	15.00	10.82	13.51	18.72	17.63
3	13.67	14.56	15.60	15.59	19.22	19.37
4	15.62	13.43	15.90	13.25	16.96	15.99
5	14.67	14.56	16.23	18.67	21.56	21.76
6	11.99	12.59	10.26	12.66	14.25	13.25
7	8.25	14.56	12.59	19.26	22.68	14.59
8	13.25	16.53	12.02	12.46	13.25	14.59
9	10.02	15.12	9.40	11.24	18.52	16.60
10	12.90	16.54	13.10	14.60	26.89	22.54
11	18.79	13.77	11.89	12.68	19.10	18.88
12	16.24	16.60	14.26	14.14	18.54	17.52
13	16.32	17.57	17.25	19.25	22.52	21.20
14	14.20	16.52	15.23	15.62	18.25	16.54
15	12.35	12.36	12.56	11.25	14.24	14.26
16	13.26	14.99	14.27	13.26	17.85	14.26
Mean (SD)	13.33 (2.67)	14.93 (1.51)	13.56 (2.34)	14.38 (2.64)	18.84 (3.46)	17.60 (3.15)
95% CI for mean	(11.91 to 14.76)	(14.12 to 15.73)	(12.32 to 14.81)	(12.97 to 15.79)	(17.00 to 20.69)	(15.92 to 19.27)

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

Figure 3 Boxplot of cervical spine movement (°) for each extrication technique. LSB, long spinal board; SEJ, short extrication jacket.



These results support the findings of the proof-of-concept study.¹² In that study a paramedic volunteer had a cervical collar applied for all extrication techniques and the least deviation recorded ($6.60^{\circ} \pm 1.03^{\circ}$) was for controlled self-extrication. In the current study, the absence of a collar and the fact that the 16 subjects participating had no prior knowledge of extrication likely account for the higher figure ($13.33^{\circ} \pm 2.67^{\circ}$) recorded for self-extrication. These results agree with similar work undertaken by a Canadian research team. Despite some differences in crew configuration, participant background and laboratory setup between our studies, the investigators also found that self-extrication with cervical collar protection resulted in less range of motion than other techniques.^{14 15} It is not possible for all patients to self-extricate due to injuries suffered in the collision. Weninger and Hertz¹⁶ found that 'high speed' collisions result in 27.7% of patients sustaining spinal injuries and 66.0% suffering traumatic brain injuries. However, it has been reported that entrapment occurs in just 12%–33% of RTC,^{17 18} so many patients will be eligible for self-extrication, depending on their clinical condition.

The influence of anthropometric measurements on cervical spine movement during extrication was also investigated. Intuitively it stands to reason that a tall, heavy individual would be more difficult to extricate from a vehicle; however, to the best of the authors' knowledge this is the first time this type of

data is reported in the literature. Both mass and height were independent predictors of movement in a model which included extrication technique as a factor. The strongest correlation between cervical spine movement and mass was for the LSB passenger technique with a tendency for heavier individuals to experience more movement during the extrication. The strongest correlation between cervical spine movement and height was for the SEJ driver technique with a tendency for taller individuals to experience more movement. The findings suggest that patient size should be considered as a factor in equipment-aided extrications and crew configuration should be adjusted accordingly if adequate resources are available.

With regard to clinical significance, the direct correlation between degrees of cervical spine movement across all three axis and injury prediction patterns is unproven. A study investigating canal space within the vertebral bodies found that narrowing of the canal diameter by 2.7 mm is significant ($p < 0.001$).¹⁹ As cadaver models are unsuitable for this research and field radiography is technically impossible, any inference is currently hypothetical and the link between degrees of motion and cord space cannot be directly calculated. However, the rational argument follows that if spinal column movement is minimised then this lessens the chance of canal narrowing after injury.

In a recent study, estimating the annual occurrence of spinal injuries in front seat occupants the SCI rate was 0.054%

Table 3 Pearson correlation coefficients (p value) for mass and height with cervical spine movement for each extrication technique

	Cervical spine movement (°)					
	Control (no collar)	Collar (support)	LSB (in-line)	LSB (passenger)	LSB (driver)	SEJ (driver)
Mass	r=0.38 (p=0.15)	r=0.48 (p=0.06)	r=0.48 (p=0.06)	r=0.61 (p=0.01)*	r=0.22 (p=0.43)	r=0.39 (p=0.13)
Height	r=0.56 (p=0.03)*	r=0.29 (p=0.28)	r=0.43 (p=0.10)	r=0.46 (p=0.08)	r=0.39 (p=0.14)	r=0.65 (p=0.007)*

* $p < 0.05$.

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

±0.010% with incidence being reduced by seat-belt use.²⁰ It is recognised that SCI occurring in RTC are relatively rare events and the indoctrinated dogma of mandatory spinal immobilisation is now changing for global EMS.

In the UK, a consensus statement has been published by the Faculty of Pre-hospital Care on the practice of spinal immobilisation.⁸ The National Association of EMS Physicians and the American College of Surgeons Committee on Trauma have also released a position statement regarding EMS spinal precautions and use of the long backboard.^{10–11} These documents recommend self-extrication for ambulant patients, after application of a cervical collar. In order for these guidelines to be implemented, there is a requirement for further education for prehospital practitioners on the current evidence around spinal immobilisation. Morrissey *et al*²¹ reported that the use of a backboard was reduced by 58% after paramedics received additional training in the principles of spine motion restriction.

As the body of evidence on spinal immobilisation builds, policy makers may wish to consider a complete paradigm shift in RTC patient management. While numerous governing bodies have already moved to revised operating procedures, these tend to revolve around adaptation of existing spinal rule-out protocols to mirror the new evidence. The authors suggest that as the evidence increases policy makers may consider that a 'spinal rule-in' policy has equal if not more benefit than a 'spinal rule-out' policy. For haemodynamically stable patients who have been assessed by trained personnel the default position could be self-extrication without the aid of rescue equipment, with the collar, spinal board and SEJ becoming the exception rather than the norm.

In the absence of appropriate studies on trauma patients, a number of RCT relating to spinal immobilisation in healthy volunteers have been reported.^{22–23} The outcomes of many of these relate to adverse effects of backboards such as increased ventilatory effort, ischaemic pain and discomfort. Of the trials that focused on the efficacy of spinal immobilisation all have used older technologies and none have focused on extrication.²² A recent review by Voss *et al*²⁴ outlined the research methods and scientific technology that have been used to assess and measure cervical range of motion. The authors emphasised the need for an experimental protocol that approximates the quality and quantity of motion generated in real-life situations. Novel approaches such as virtual reality, electromagnetic tracking technology and simulation are also discussed.²⁴ New technologies may make possible a definitive RCT of trauma patients in the field, by overcoming the practical issues associated with these types of measurements; however, the ethical ramifications must still be considered.

The limitations of this study include the relatively small sample size and somewhat narrow age range of the participants. It is unknown how transferable these findings are to the clinical setting due to the inherent limitations of performing this type of research in a laboratory. However, every effort was made to ensure the extrication scenarios were as realistic as possible. In terms of on-going research, the distribution of the data collected on the 16 participants described here could be used to simulate data for a larger sample of participants. The use of alternative technologies such as accelerometers which may be adapted for field use in the future is also currently being investigated.

CONCLUSIONS

For haemodynamically stable patients controlled self-extrication causes less movement of the cervical spine than extrications performed using traditional EMS equipment. These data support

the findings of the proof-of-concept study. These results add to the growing body of evidence suggesting that current rescue techniques may not be providing optimal care for the post-RTC patient.

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Contributors All of the authors were involved in the design of the study. SK coordinated the logistics of the study. JOH conducted the biomechanical analysis and AH performed the statistical analysis. NMC and MD drafted the manuscript and all authors reviewed the draft and approved the final submitted version.

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