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Research article

Biomechanical analysis of spinal misalignment during Vehicular extrication maneuvers performed by professional rescue teams

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ABSTRACT

Objective: To compare spinal misalignment and execution time of 3 rescue maneuvers for casualties in traffic accidents.
Materials and methods: Biomechanical analysis using inertial sensors to measure the range of spinal misalignment and execution time of 3 maneuvers: 1) standard manual rescue (SMR); 2) rapid extrication device (RED); 3) extrication device (ED). The sample consisted of 117 rescue professionals (firefighters) from 14 Autonomous Communities in Spain. The total range of motion and the execution time of maneuvers were compared using ANOVA.
Results: The highest range of cervical flexion-extension movement was recorded with RED (30° ± 9°). There were no statistically significant differences between SMR (21° ± 9°) and ED (21° ± 10°). In dorsal flexion-extension, the highest range of movement was with RED (36° ± 10°), followed by ED (30° ± 7°), with the lowest found for SMR (26° ± 11°). RED presented the least restriction of cervical ($p < 0.001$) and dorsal movement ($p < 0.001$). The quickest maneuver was SMR (average of 55″), followed by RED (average of 92″), with a considerable difference using ED (average of 225″) ($p < 0.001$).
Conclusion: The standard manual rescue maneuver (SMR) generated the smallest range of spinal movement and also required the shortest execution time.

SHORT ABSTRACT.
"Determination with motion capture of the extrication practice that involves less spinal movement and time."
WHAT IS ALREADY KNOWN.

- Some international treaties have postulated maneuvers for the extrication of casualties in motor vehicle accidents, but the range of motion caused by the techniques recommended in manuals has not been defined, and efficiency in terms of spinal movement and maneuver time has not been described in isolated or combined terms.

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- Restricting spinal movements is essential when mobilizing a patient with suspected spinal cord injury, yet there is no literature on extrication time using the maneuvers recommended by international treaties.
- Time on scene increases mortality in patients with major trauma, highlighting the need for efficient and rapid extrication techniques.

WHAT THIS PAPER ADDS.

- Measurement of all ranges of global and sectioned spinal movement (cervical, dorsal and lumbar) in the extrication maneuvers studied and extrication time in traffic accident rescues.
- Correlation of spinal range of motion and time of the maneuver used.
- Definition of the most efficient maneuver for the extrication of patients rescued in traffic accidents

1. Background

Traumas and violence rank among the top causes of mortality globally, as evidenced by the fact that this medical issue affects over 45 million people with moderate to severe disabilities [1]. In particular, trauma resulting from road traffic collisions (TC) is responsible for the deaths of approximately 1.3 million individuals each year across various nations. Consequently, the development and implementation of strategies aimed at enhancing the quality of trauma care have become a paramount goal for healthcare professionals within Emergency Medical Services (EMS) [2]. Most of the deaths occur at the scene or in the following 4 h after the event [3,4].Additionally, the initial vehicle extrication techniques deployed during a road traffic collision are deemed crucial for reducing the likelihood of death and severe injury [5]. This underscores the urgent need for improved emergency response and patient handling protocols to save lives and mitigate the long-term impact of such traumatic events.

The terms "*golden hour*" and "*platinum 10 min*" are critical concepts in trauma care, emphasizing the importance of minimizing the time spent at the scene—from the moment the Emergency Medical Services (EMS) arrive to the initiation of the patient's transfer to the hospital. In cases involving patients with severe or major trauma, this strategy is crucial as it involves the rapid identification and preliminary treatment of life-threatening injuries, which are particularly time-sensitive. This approach is designed to enhance survival rates by ensuring timely medical intervention for the most critical conditions [6–11]. During this initial period, the restriction of spinal movement (RSM) is a fundamental objective when a spinal cord injury (SCI) is suspected; SCI is suspected until it can be ruled out [6]. Historically, RSM was applied indiscriminately, although the most current evidence indicates that selective immobilization must be performed only in patients who meet specific criteria. Algorithms (i.e. *Canadian C-Spine Rules, NEXUS*, etc.), although not originally designed for deciding on spinal immobilization, are employed as a tool in decision-making regarding RSM [12,13].

The 10th *Edition* of the *Pre-Hospital Trauma Life* Support *(PHTLS)* manual comprehensively describes, among its various recommendations, a range of different and effective casualties extrication maneuvers following a traffic collision (TC) [6]. On one side of the spectrum, there exists the traditional approach of the standard manual rescue (SMR) maneuver, while on the other, the practice of extrication employs a rapid extrication device (RED), frequently referred to as the "Rescue Boa". Despite the prevalence of these techniques, there has been a noticeable lack of comparative studies analyzing the extent of spinal movement involved and the duration required to perform each maneuver. Furthermore, rescue teams frequently implement the extrication device (ED) in their operations, yet they do so without the backing of empirical data to affirm its efficacy or safety, particularly concerning the risk of spinal misalignment during the procedure. This absence of validated research raises concerns about the best practices for spinal care during rescue operations, urging a need for thorough investigation into both the effectiveness and safety of these widely used rescue maneuvers [4,6]. The objective of the present study was to compare the spinal misalignment and execution time of 3 different rescue maneuvers of TC casualties (SMR, RED, and ED).

2. Material and method

Comparative multi-center simulation study consisting on the extrication of a simulated patient from a vehicle through the use of 3 maneuvers (SMR, RED, and ED). Through a biomechanical study with inertial sensors (IS), the range of spinal misalignment was measured during the extrication of the same simulated patient with the following anthropometric characteristics: healthy caucasian adult, age: 31, height: 1.73 cm, weight: 75 Kg, Body Mass Index (BMI): 25.1.

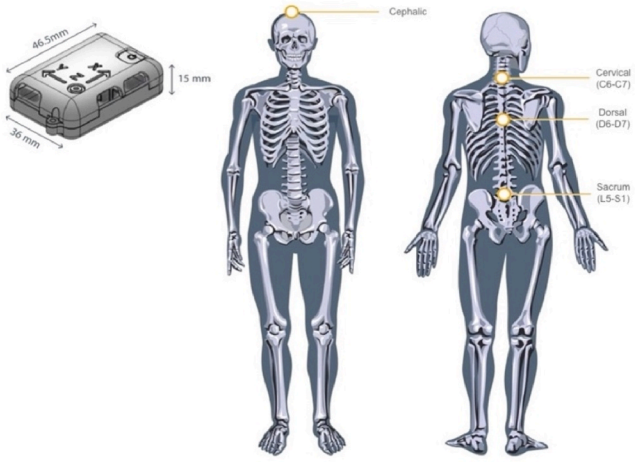
The casualty played the role voluntarily, previously signing an informed consent. The present work was approved by the Ethics Committee from the San Antonio Catholic University of Murcia (UCAM) (registration number 6118). All the participants provided, in writing, their informed consent to participate in the study, and completed a companion form with personal and biometric data.

2.1. Sample selection

Through an open call, a sample was obtained of professional rescue teams belonging to the Association of Traffic Accident Rescue Professionals (APRAT), this association is included in the World Rescue Organization. All of them were firefighters who act as a first responders in TC in different autonomous communities in Spain (Supplementary Material 1), finally counting with a representation of teams from practically the entire Spanish territory.

Through a simple randomization, the volunteer-rescuers were assigned to one of 39 intervention teams (3 rescuers per team). All

1-A. I.S. (size and location)



SMR **RED** **ED**

1-B. Maneuvers performed .

Fig. 1. Maneuvers and analysis in the experimental phase.
IS: Inertial Sensors; SMR: Standard Manual Rescue; RED: Rapid Extrication Device; ED: Extrication Device.

teams were led by the same healthcare provider to avoid differences in technique.

The inclusion criteria considered were.

- Having received rescue training in the last year as first responders in a TC.
- Actively participating in TC rescue meets in 2023.
- Signing the informed consent form before performing the rescue.

The exclusion criteria considered were.

- Physical lesion that made it impossible to complete the exercise.
- Lack of time to completely perform the experiment (3 maneuvers per team).
- Lack of aptitudes or attitudes to follow the indications by the research team.

2.2. Inertial systems

The analysis of movement was conducted using the STT-IBS iSen 3D Motion Analyzer® (STT Systems), an advanced Inertial System (IS) that combines multiple sensors to capture motion data with high precision. This IS contains an accelerometer, a gyroscope, and a magnetometer, all housed in a robust casing. It operates at a broadcast frequency of 250 Hz, ensuring a high rate of data capture. The system boasts impressive static precision for roll, pitch, and yaw, all measuring below 0.5°, and dynamic precision for these same measures, all within 1.5°. Additionally, it has a latency of less than 0.004 s, allowing it to deliver data in near real-time.

The system determines the angular orientation of an object by providing values for the three spatial coordinates—X, Y, and Z—transmitting data through a Wi-Fi connection on a local network. This connectivity facilitates seamless data transfer, enabling the system to generate and process movement data simultaneously and automatically as the subject moves. The biomechanical model used for this analysis focused on spinal movement, with the goal of measuring the full range of motion (FRM) of the spinal column, specifically in the cervical, dorsal, and lumbar segments.

To capture these measurements, four IS units were placed on specific anatomical landmarks, as illustrated in Fig. 1-a. These units were carefully calibrated before each analysis, starting with the subject in a neutral sitting position within the vehicle cabin. This calibration step is crucial to ensure the accuracy and reliability of the data collected during movement analysis. The standardized patient was then monitored during various maneuvers, with the IS capturing the motion data in real-time, providing a comprehensive understanding of the spinal movement through the coordinated use of this advanced technology.

2.3. Extrication maneuvers of the simulated patient

To avoid variability between teams and to control for confounding factors, the maneuver was performed with directions from a single health professional-instructor. To perform the maneuvers, the standardized patient was seated in the driver's seat of a 5-door passenger car (2006 *SEAT Ibiza*®) on four wheels previously stabilized by the TC rescue professionals. The casualty wore a cervical collar (*Stifneck select*® by *Laerdal*®). The exercise started as soon as the driver's side door was opened, and ended with the presentation of the spinal board (SB) at the vehicle door, before transferring the patient to it. This common point was taken to end the experiment because the rest of the maneuver until the patient is on the SB in the supine position is common to the three maneuvers (sliding the patient on the board). Moreover, it was detected that at this point, the sensors could generate reading biases due to the friction of the sensor on the SB.

The three maneuvers (Fig. 1-B) that each team performed were the following.

1. SMR maneuver: fast maneuver in which the casualty is extricated through the driver's door without the use of additional devices.
2. RED maneuver: fast vehicle extrication using a *SNAID*® fast extrication device through the driver's door.
3. ED maneuver: vehicle extrication through the use of the *Ferno KED 500*® extrication device.

2.4. Statistical analysis

The data are presented as means and standard deviations (SD) for continuous variables, and frequencies and percentages for categorical variables. The main variable was the FRM of the flexion-extension of the neck in degrees, and the secondary one, the time needed to perform the maneuver. The remaining variables analyzed were FRM in the other axes of movement of the neck, shoulders, and trunk.

The normality of the data was determined with the Shapiro-Wilk test, and the homogeneity of the variance with Levene's test. Also, an analysis of variance (ANOVA) was performed to assess the differences in the results between the groups defined by the categorical variables of interest, such as profession and sex. When the ANOVA indicated significant differences, a *post hoc* Tukey test was performed, to identify specific differences between the groups. The data were analyzed with the *SPSS*® v.25 program. The statistical significance was defined with a $p < 0.05$.

A clustering analysis was conducted. All the information regarding this analysis is detailed in Supplementary Material 2.

3. Results

The sociodemographic and anthropometric data of the professionals involved in the study are illustrated in Supplementary Material 1. The analysis aimed to compare different maneuvers and evaluate their impact on cervical and dorsal flexion-extension. The results demonstrated statistically significant differences in these metrics, as detailed in Table 1. Specifically, the study highlighted that the RED maneuver resulted in the highest range of cervical flexion-extension, with a mean of 30° (±9°). This was notably higher than the range observed with the SMR maneuver, which was 21° (±9°), and the ED maneuver, which measured 21° (±10°). The significant difference in range of motion among these maneuvers ($p < 0.001$) indicates that the RED maneuver imposes fewer restrictions on cervical spine movement (see Table 2).

Similarly, the analysis of the full range of motion (FRM) in dorsal flexion-extension also showed significant differences among the maneuvers. The RED maneuver had a greater range of dorsal flexion-extension, with an average of 36° (±10°). In contrast, the SMR maneuver exhibited a range of 26° (±11°), while the ED maneuver showed a range of 30° (±7°). These findings suggest that the RED maneuver is less effective at limiting trunk mobility, indicating a lower degree of immobilization compared to the other maneuvers.

These findings indicate that the maneuvers performed differ in their capacity to limit mobility in these critical areas, with the RED

Table 1
Comparison of means of the different spinal movements with each maneuver.

Variable	Motion	Mean ± SD			p
		SMR	RED	ED	
FRM Head	AP Inclination	41.28°± 49.29°	57.45°±59.82°	43.06°± 39.19°	0.311
	Flexion-extension	11.15°± 6.62°	12.74°± 6.30°	15.06°± 7.88°	0.055
	Lateral Flexion Right and left	19.44°± 10.67°	16.61°± 5.61°	17.58°± 8.54°	0.339
	Rotation	24.64°± 10.72°	25.58°±11.51°	27.94°± 21.28°	0.625
FRM Cervical	Flexion-extension	20.77°± 9.36°	29.68°± 9.16°	21.39°± 9.73°	**p<0.001**
	Lateral Flexion Right and left	26.21°± 12.45°	27.63°± 9.52°	26.08°± 9.57°	0.781
	Rotation	34.85°± 9.96°	34.16°±15.07°	37.00°± 21.89°	0.736
FRM Shoulders	Lateral tilt	14.23°± 39.28°	9.08°± 19.63°	7.97°± 13.93°	0.558
FRM dorsal	Flexion-extension	25.95°± 10.75°	35.50°± 9.50°	29.92°± 7.06°	**p<0.001**
	Lateral Flexion Right and left	21.72°± 9.69°	22.87°± 9.33°	19.47°± 5.55°	0.219
FRM Lumbar	Flexion-extension	24.72°± 8.60°	24.00° ± 7.93°	24.56°± 6.69°	0.915
	Lateral Flexion Right and left	31.33°± 18.25°	25.42°±11.25°	25.03°± 9.67°	0.082
	Rotation	37.62°± 12.26°	35.66°±11.63°	40.97°± 13.52°	0.185

Table 2
Comparison of means of cervical and dorsal flexion-extension movement by clusters.

Spinal Segment	Compared clusters		Mean difference	Limits		p
				Upper	Lower	
Cervical	0	1	- 14.60°	- 19.81°	- 9.39°	**0.001***
	0	2	- 20.34°	- 25.63°	- 15.06°	**0.001***
	0	3	- 16.05°	- 21.41°	- 10.69°	**0.001***
	1	2	- 5.74°	- 10.58°	- 0.90°	**0.013***
	1	3	- 1.45°	- 6.38°	3.48°	0.855
	2	3	4.30°	- 0.71°	9.30°	0.119
Dorsal	0	1	- 3.93°	- 10.83°	2.96°	0.449
	0	2	- 8.87°	- 15.86°	- 1.88°	**0.007***
	0	3	- 3.94°	- 11.04°	3.16°	0.473
	1	2	- 4.94°	- 11.35°	1.47°	0.191
	1	3	- 0.01°	- 6.54°	6.52°	0.900
	2	3	4.93°	- 1.70°	11.56°	0.218

maneuver showing a higher FRM mean in both measurements, which suggests a lower efficacy in the restriction of spinal movements as compared to the SMR and ED maneuvers. No significant differences were found in the other measurements of FRM.

With respect to the execution time, a significant variability was observed in the mean execution times needed to complete each maneuver, with the SMR maneuver highlighted due to its speed, as compared to the RED maneuver, with the difference being more pronounced with the ED maneuver ($p < 0.001$). The RED maneuver, with a mean of 92″, showed significantly longer execution times (1.63 times) as compared to the fastest maneuver, SMR (mean of 55″). The recordings indicated that the ED maneuver, with a mean of 225”, was completed in a significantly longer period of time as compared to the SMR (4 times longer) and RED (2.5 longer) maneuvers.

Fig. 2 provides a graphical summary of the study results, including spinal range of motion related to flexion-extension in the cervical, thoracic, and pelvic regions for each maneuver, as well as the time required to complete each maneuver.

4. Discussion

The results presented in the previous section are essential to understand the implications of each maneuver on spinal movement and provide valuable information for professionals working in environments where spinal immobilization is crucial. The statistically

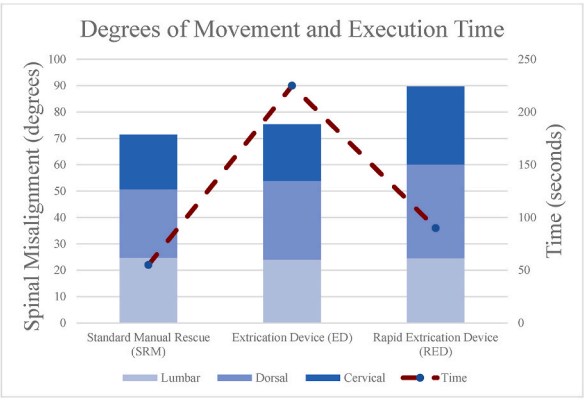


Fig. 2. Graph of Study Results: spinal range of motion concerning flexion-extension movement and execution time of patient extrication maneuvers.

significant differences emphasize the importance of selecting appropriate maneuvers to ensure patient safety while minimizing the risk of further injury due to excessive spinal motion.

Presently, different extrication maneuvers are recommended in TC cases [14]. However, in most of the cases, there is no data on the real range of mobilization and execution time for each maneuver. When arriving to a TC, the rescuers must choose a maneuver and decide on the balance between movement restriction and time needed; There is no clear evidence on the best treatment in the case of a SCI, although the fact that time increases mortality during the first hour is well known [2–8,10–12]. Therefore, the protection of the spinal column, by limiting spinal movement as much as possible, must be considered in health care [6,9,13]. It is essential to understand that some patients need a fast extrication, due to their critical state, while the state of others could allow for a more controlled extrication strategy [5,15]. In this sense, some tools, such as the diagram created by Vaughan et al., could help in the making of decisions by the EMS [15].

When analyzing the spinal movement, it was observed that in the SMR maneuver, the full range of spinal motion was significantly lower than in the RED and ED maneuvers. In the scientific literature, no studies were found that compared these three maneuvers. In the studies conducted by Dixon et al. [16,17], the vehicle extrication of a simulated patient was measured through a biomechanical analysis with 3D cameras, through diverse techniques similar to those performed in our study. In the study by Engsberg et al. [18], the extrication was measured, by comparing the cervical movement with and without the protection of a cervical collar, and with assistance from rescuers (SMR and ED). In these three articles, it must be considered that the results were not completely comparable, as the systems used to capture movement were different, and these authors only provided recordings of the total cervical movement, but not of the entire spinal column, as in our study. Also, the sample used was small, so that the results must be considered with caution. Nevertheless, results similar to ours can be observed, with a lower range of motion with SMR with respect to ED. The complete spinal column movement (cervical, thoracic, and lumbar) was analyzed in the study conducted by Häske et al. [19], where the authors used IS to study various maneuvers of casualty extrication from a vehicle; among them, SMR and RED. A higher total movement was recorded, and especially in the lumbar region, with RED as compared to SMR, in agreement with our findings. However, the study reported that the range of cervical movement was reduced with RED.

Regarding the variable of time, the extrication with SMR was significantly quicker than with the other maneuvers. The traffic collision rescue personnel tend to be more trained in the ED maneuver compared to RED. Unfortunately, most studies analyzing extrication and rescue through biomechanical analysis do not record the time taken, making it impossible to compare these with our results. However, another study found similar results to those in this study in terms of SMR, both in the range of motion and in the mean time required. Yet, their conclusions suggest that self-extrication might be the best option, a maneuver not explored in this study [20].

The implications of these findings are significant for the safety of extrication operations. Since SMR is faster, it could be the preferable option in situations where time is critical. At the same time, rescue personnel's training in ED instead of RED may suggest that more focus is needed on improving skills in the latter, as the studies indicate lower success rates with it.

The lack of time-related data in biomechanical analyses makes it challenging to establish a direct correlation between extrication method and efficiency, suggesting that future studies should prioritize this aspect. The recommendation from other studies on self-extrication indicates an area where additional research is needed, especially in scenarios where traditional extrication methods might pose risks to the patient due to spine movement.

Therefore, it's crucial to balance efficiency and safety in extrication methods. Given these findings, further research should focus on detailed biomechanical studies and measure the time to evaluate which extrication techniques offer the best outcomes for both the casualties and the rescue personnel involved in these critical operations.

It is considered that the key to patient care is considering a global approach, whose objective is to find the balance between safety in the maintenance of spinal alignment, and the execution time of the maneuvers. When assessing the main variables (time and spinal movement), it was observed that the SMR maneuver was significantly more efficient than RED and ED, as the casualty could be rescued in the least amount of time possible, and the same time reducing the risk of spinal range of motion to the maximum degree [6,9,13,20,21]. The superiority of the SMR maneuver, in terms of speed of execution and lower FRM, provides important considerations for clinical practice and the training of immobilization and rescue maneuvers, especially in high-pressure scenarios dependent on time, and each second is important [22–24].

The action guides and protocols when dealing with a severe trauma have evolved in the past few decades[25–27]. Therefore, it is essential to consider the differences found in the management of TC casualties, in order to further develop and refine rescue protocols in this area, because ensuring that the maneuvers recommended are adequate could greatly benefit the patients.

Future lines of research must focus on broadening knowledge with respect to FRM, the extrication maneuvers, and time, to ultimately improve rescue practices and to minimize the risk of secondary lesions with a reasonable extrication time. The study of the self-extrication maneuver through a biomechanical analysis is considered an interesting path to take in the area of TC rescues [16–21]. In addition, qualitative studies should be performed to better understand the perceptions and experiences of patients and rescuers.

In conclusion, the standard manual maneuver is defined as the ideal maneuver for rescuing casualties from a vehicle, as it obtained the best results in both the maintenance of the spinal column alignment, as well as execution time. The extrication vest maintains the alignment of the spinal column better than the fast extrication device, although the execution time is prolonged substantially.

CRediT authorship contribution statement

Manuel Pons Claramonte: Writing – review & editing, Writing – original draft, Visualization, Validation, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Manuel Pardo Ríos:** Writing – original draft, Validation,

Supervision, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Ana Nicolás Carrillo:** Writing – review & editing, Writing – original draft, Visualization, Validation, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Alberto Nieto Navarro:** Visualization, Validation, Methodology, Investigation. **Itziar Baztán Ferreros:** Visualization, Validation, Methodology, Investigation. **Sergio Nieto Caballero:** Writing – review & editing, Visualization, Validation, Supervision, Resources, Methodology, Investigation.

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Data Availability

The authors declare that anonymized data is available upon request via email.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: ANA NICOLAS CARRILLO reports financial support was provided by Spanish Society of Emergency Medicine (SEMES). If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e39045.

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