Archives of Academic Emergency Medicine. 2024; 12(1): e36

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ORIGINAL RESEARCH

Traditional Spinal Immobilization versus Spinal Motion Restriction in Cervical Spine Movement; a Randomized Crossover Trial

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Received: January 2024; Accepted: February 2024; Published online: 12 March 2024

Abstract: **Introduction:** Proper cervical spine immobilization is essential to prevent further injury following trauma. This study aimed to compare the cervical range of motion (ROM) and the immobilization time between traditional spinal immobilization (TSI) and spinal motion restriction (SMR). **Methods:** This study was a randomized 2x2 crossover design in healthy volunteers. Participants were randomly assigned by Sequential numbered, opaque, sealed envelopes (SNOSE) with permuted block-of-four randomization to TSI or SMR. We used an inertial measurement unit (IMU) sensor to measure the cervical ROM in three dimensions focusing on flexion-extension, rotation, and lateral bending. The immobilization time was recorded by the investigator. **Results:** A total of 35 healthy volunteers were enrolled in the study. The SMR method had cervical spine movement lower than the TSI method about 3.18 degrees on ROM in flexion-extension ($p < 0.001$). The SMR method had cervical spine movement lower than the TSI method about 2.01 degrees on ROM in lateral bending ($p = 0.022$). The immobilization time for the SMR method was 11.88 seconds longer than for the TSI method ($p < 0.001$) but not clinically significant. **Conclusion:** SMR that used scoop stretcher resulted in significantly less cervical spine movement than immobilization with a TSI that used long spinal board. We recommend implementing the SMR protocol for transporting trauma patients, as minimizing cervical motion may enhance patient outcomes.

Keywords: spinal immobilization, prehospital care, traditional spinal immobilization, spinal motion restriction

Cite this article as: Nuanprom P, Yuksen C, Tienpratarn W, et al. Traditional Spinal Immobilization versus Spinal Motion Restriction in Cervical Spine Movement; a Randomized Crossover Trial. Arch Acad Emerg Med. 2024; 12(1): e36. https://doi.org/10.22037/aaem.v12i1.2263.

1. Introduction

Traumatic spinal cord injuries (TSCI) represent a significant focus of attention in the management of traumatic patients, both in the prehospital setting and within the emergency department (ED). The prevalence of TSCI as determined by the study conducted by Natsinee et al. in Thailand was 7.7% among patients suspected of having TSCI [1]. The overarching objective of TSCI care is to mitigate the risk of secondary spinal cord injury that may ensue from fragmentation or further injury to the spinal cord. TSCI is frequently encountered in cases of severe blunt trauma, particularly when the trauma directly affects the cervical spine or involves hyperflexion and hyperextension of the cervical spine [2]. Neglecting proper care, including the use of cervical spine protection during the transportation of TSCI patients, can have profound repercussions. It substantially elevates the chances of mortality and disability, thereby increasing the likelihood of spinal cord injury and subsequent neurological deficits [3].

In the initial management of TSCI patients within the prehospital setting, the foremost step involves two critical interventions: control the external hemorrhage and achieving cervical spine immobilization [4, 5]. Cervical spine immobilization is crucial for patients with suspected spinal injuries, not all traumatic patients, and it is warranted in cases characterized by high-impact blunt mechanisms directly affecting the cervical spine, alterations in mental status, neurological deficits, cervical spine tenderness, and distracting pain in other major organ systems [1, 6-9].

When attending to patients with suspected TSCI at the scene, it is standard practice to manually immobilize the cervical spine during the primary survey assessment and on-scene resuscitation efforts [10]. Additionally, it is advisable to employ a cervical rigid collar before initiating transportation for added stability and protection [11-13].

The conventional approach to transporting TSCI involved the utilization of Traditional Spinal Immobilization (TSI) techniques employing a long spinal board (LSB) [14]. The TSI protocol entailed a series of steps, which included a 90-degree logroll maneuver to reposition the TSI patient, the insertion of the LSB beneath the patient, a subsequent 90-degree logroll to return the TSCI patient to the LSB, and the application of buccal straps and head immobilization to secure the patient in an immobilized state. Numerous studies have supported the safety and efficacy of TSI in facilitating

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the prehospital transportation of TSI patients [14-16].
However, recent literature has brought attention to potential complications associated with TSI. These complications include the development of pressure ulcers in patients subjected to extended transportation times [17, 18], patient discomfort and respiratory distress stemming from prolonged immobilization [19], extended time requirements for TSI preparation and application, and concerns regarding the potential impact of the 90-degree logroll maneuver on cervical spine movement.
Spinal Motion Restriction (SMR) represents an innovative technique employed in transporting patients with TSI. In contrast to the traditional method utilizing an LSB, SMR employs a scoop stretcher, a device characterized by its bifurcated structure that can be separated and then gently maneuvered beneath the patient. Typically composed of rigid materials such as plastic or aluminum, the scoop stretcher features multiple locking mechanisms to secure its two halves in position [20]. The use of a scoop stretcher resulted in reduced time for packaging trauma patients and a decreased incidence of pain, pressure ulcers, elevated intracranial pressure, and prolonged prehospital on-scene time. During the logroll maneuver, it was observed that angling the patient between 15-20 degrees is safer compared to a 90-degree angle in TSI with LSB [5-7].
The SMR protocol entailed a meticulous sequence of steps. Initially, a controlled 15-20 degree logroll maneuver is executed to elevate the TSI patient, allowing for the insertion of the split-apart segments of the scoop stretcher. Subsequently, the patient is logrolled back down onto the stretcher. This process is then repeated on the opposite side of the patient. Further immobilization measures are implemented following the successful placement of the TSI patient in the appropriate position on the scoop stretcher. These include the use of head immobilization techniques, which employ straps to restrict cervical spine movement, as well as the application of buccal straps to minimize bodily movement during transport [4, 19, 21-23].
The appropriateness of spinal immobilization techniques for out-of-hospital TSI patients remains a subject of ongoing debate, and there is a notable lack of comprehensive studies evaluating the effectiveness and safety of LSB in this context. This study aimed to compare the ROM and the immobilization time between TSI and SMR.

2. Methods

2.1. Study design and setting

This study employed a method-oriented approach, employing a randomized 2x2 crossover design at the College of Sports Science and Technology, Mahidol University, Thailand, from November to December 2022. The participants underwent two different methods of transportation with a time difference. Compared to the parallel design, the advantages of this approach include a reduction in the number of participants needed to achieve equivalent statistical power and precision. However, the disadvantages encompass potential sequence or carryover effects, necessitating a washout period for control [25]. In our study, both participants and research assistants were in good health. The washout period did not substantially impact the outcomes related to ROM or the time required to implement TSI and SMR techniques [24].
Ethical approval for this study was granted by The Faculty of Medicine, Committee on Human Rights Related to Research Involving Human Subjects, Ramathibodi Hospital, Mahidol University, on November 29, 2022, under the reference number IRB COA. MURA2022/688.

2.2. Participants

We recruited healthy adult volunteers from Mahidol University for the study, provided them with informational brochures, and obtained their signed informed consent prior to their enrollment in the research protocol. Participants with a documented history of spinal injury, scoliosis, kyphosis, flat-back syndrome, or chin-on-chest syndrome were excluded from the study due to their inability to assume a supine position on the stretcher. Additionally, female participants were not included in the study, as the placement of the IMU motion sensor on the sternum posed potentially inappropriate exposure for female participants.
Participants were randomly assigned to one of two groups. Group AB underwent TSI as the initial method, followed by SMR as the subsequent method. Group BA experienced SMR first, followed by TSI, with a 60-minute washout period between the two methods. The allocation sequence was generated using a Sequential numbered, opaque, sealed envelopes (SNOSE) approach, employing permuted blocks of four for randomization. We acquired 34 indistinguishable, non-transparent, letter-sized envelopes; 34 sheets of standard-size paper; 17 letter-size sheets commencing with TSI and 17 letter-size sheets commencing with SMR. Insert the completed document into the envelope. Seal the envelope and sign across the seal [26].

2.3. Intervention and definitions

The initial step for each group of participants involved assuming a supine position with the head in a neutral alignment and the application of a suitably fitted cervical rigid collar (Ambu® Perfit ACE, Ballerup, Norway).

ROM measurement

An inertial measurement unit (IMU) sensor was affixed to the participant's forehead and chest regions (Figure 1). The precise placement of the IMU sensor was consistently verified to ensure uniform positioning across all individuals. The IMU functions as a sensor that integrates a gyroscope, magnetometer, and accelerometer. Gyroscopes ascertain sensor orientation by integrating signals representing angular velocity in relation to the sensor's XYZ axis. Accelerometers provide a static orientation measurement relative to gravity through analysis of acceleration signals, while magnetometers establish orientation based on sensor alignment with Earth's magnetic field. Through the application of sophisticated data fusion algorithms that amalgamate signals from each sensor, a dependable estimate of IMU sensor orientation can be achieved [27]. Consequently, disparities in sensor orientation aligned with bone can be utilized to compute joint angle, angular rate, and body orientation. The ROM across three axes was determined by analyzing the relative angle between two IMU sensors placed on the head and sternum using the Noraxon MyoResearch software. To minimize potential errors, a trained professional positioned all sensors at identical anatomical landmarks. Additionally, prior to data recording, the sensors were calibrated to establish each participant's baseline angle. Furthermore, a residual anti-wobbling correction of 300 milliseconds was applied to the data at a frequency of 5 Hz using the Noraxon MyoResearch software to enhance smoothing and eliminate soft tissue artifacts [28].

The calibration of the sensor is performed after the sensor is applied to the anatomy landmark. The participant was asked to stay still in an anatomical posture to set the baseline angle. To reduce the offset from subcutaneous fat and movement of muscle, a sensor was placed on the bony area. The original calibration file was reapplied to the system before the start of each trial by Noraxon MyoResearch software [28] [27].

Participants assumed a neutral position with the cervical rigid collar in place, and the IMU sensors were meticulously calibrated utilizing the MR3.6 software from Noraxon USA, Inc., Scottsdale, AZ. The sensors were securely adhered in position using double-sided tape.

For further details regarding this device, please refer to the webpage: https://www.noraxon.com/noraxon-download/myomotion-system-user-manual.

Continuous manual in-line stabilization

Furthermore, continuous manual in-line stabilization (MILS) was meticulously administered by one of the research assistants with the aim of minimizing the range of cervical motion exhibited by the participants. During the MILS technique, research assistants positioned themselves above the participant's head, gently using their palms to grasp alongside the participant's head to stabilize and restrict neck motion [3, 4]. The research team adhered to established protocols and guidelines to guarantee the correct implementation of both immobilization techniques. Close and vigilant monitoring of participants was upheld throughout the immobilization period, with a paramount focus on compliance and ensuring their safety.

Immobilization in TSI group

The TSI group underwent a standardized immobilization procedure involving a rigid cervical collar, an LSB, and a head immobilizer (Spencer Industries Inc., Dale, Indiana). The immobilization process was executed as follows [24]:

1. We positioned the first assistant around the participant's head, ensuring continuous MILS throughout the procedure.

2.The second assistant applied pressure by placing their knee at the center of the participant's chest, simultaneously using one hand to grasp the shoulder and the other to hold the gluteal fold.

3.The third assistant positioned themselves at the participant's hip and knee region, gripping the anterior superior iliac spine with one hand and the femur with the other.

4. Following the initial steps, the first assistant was directed to rotate the participant 90 degrees.

5. The fourth assistant introduced the LSB between the participant's knees and feet.

6. Subsequently, the first assistant was instructed to roll the participant onto the LSB, ensuring a gradual and controlled transfer onto the ground.

7. The second assistant held the participant's armpits on both sides, while the third assistant provided support at the hip area, facilitating the diagonal movement of the participant individually onto the LSB.

8. Three fixation straps were affixed at strategic points above the nipple line, over the hips, and at the knee region to secure the participant.

9. Finally, the head immobilizer was attached and securely strapped to the forehead and positioned under the chin, as illustrated in Figure 2."

Immobilization in SMR group

The SMR group employed a standardized immobilization protocol using a cervical rigid collar, a scoop stretcher (Scoop EXL, courtesy of Ferno-Washington, Inc., Wilmington, OH), and a scoop stretcher (Spencer Carrera XL, Spencer Industries Inc., Dale, Indiana). The procedure was conducted as follows [29]:

1. We positioned the first assistant around the participant's head, maintaining continuous MILS throughout the process.

2. The second assistant applied pressure by positioning their knee at the center of the participant's chest, using one hand to grasp the shoulder and the other to secure the gluteal fold.

3. The third assistant positioned themselves at the participant's hip and knee area, gripping the anterior superior iliac spine with one hand and the femur with the other.

4. The fourth assistant inserted a portion of the scoop stretcher beneath the participant's body.

5. The first rescuer was then instructed to rotate the participant by 15 degrees.

6. The fourth assistant inserted another section of the scoop stretcher beneath the participant's body, ensuring symmetrical placement on both sides and subsequently locked the components of the lap stretcher together.

7. At least three straps were employed to secure the injured individual firmly to the stretcher.

8. The participant was lifted onto the ambulance emergency bed with the assistance of two additional attendants. A separate assistant provided continuous MILS throughout the lifting and moving process.

9. After the participant was safely transferred, the scoop stretcher was removed.

10. Subsequently, three straps were utilized to secure the

Figure 1: Position for installing inertial measurement unit (IMU) on the forehead and the chest.

participant to the ambulance emergency bed.

11. Finally, the head immobilizer was affixed and securely strapped to the forehead, with the chin strap applied last, as depicted in Figure 2.

The immobilization time

In the TSI group, the immobilization time was delineated as the duration commencing from the point at which the LSB was inserted following the participant's log rolling procedure (designated as time zero) up to the moment of successfully relocating the participants onto the ambulance bed (defined as the endpoint time). Conversely, in the SMR group, the immobilization time was defined as the interval that transpired from the insertion of the scoop stretcher after rotating the participant by 15 degrees (time zero) to the point of successfully transferring the participants onto the ambulance bed (the endpoint time).

The duration of immobilization was assessed using a 2D camera synchronized with IMU sensors to identify the phases for analysis.

2.4. Statistical analysis

For sample size estimation, according to Swartz EE et al. [30] a difference of 5 degrees in the cervical spine ROM between the two groups was considered as significant. Therefore, a sample size of at least 34 participants per group would be required to detect a significant difference in cervical spine ROM between the TSI and SMR groups with 80% of power, a significance level of 0.05, a ratio 1:1, and a two-side test.

Descriptive statistics were used to summarize participant demographics and baseline characteristics. Dependent numerical variables were compared by using the Paired t-test for parametric variables and the Sign rank test for non-parametric variables. Mixed-effects regression models were used to analyze the effect of spinal immobilization technique and period on cervical spine movement. Statistical data analysis using STATA version 14.0 (StataCorp, College Station, TX, USA). The results of the analysis were reported with p-values and confidence intervals. A p-value of <0.05 will be considered statistically significant.

3. Results

We recruited 35 healthy male students from Mahidol University. The participants had an average age of 21±2.45 years. The average weight of participants was 69.40±9.39 kilograms (kg). Their average height measured 174.01± 6.23 centimeters. Additionally, the participants exhibited an average Body Mass Index (BMI) of 22.87±2.27 kg/m^2.

As presented in Table 1, the primary outcome results revealed the mean ROM for cervical flexion and extension during immobilization using TSI and SMR. Specifically, the mean range for flexion-extension was 13.92±4.97 degrees for TSI and 10.74±3.33 degrees for SMR. Notably, the SMR method demonstrated a statistically significant reduction of 3.18 degrees compared to the TSI ($p < 0.001$). In the case of cervical rotation, the mean ROM for TSI and SMR was 13.83± 3.87 degrees and 14.05±3.74 degrees, respectively ($p = 0.769$). Regarding lateral bending, the mean ROM for TSI and SMR was 16.09±4.69 degrees and 14.07±5.17 degrees, respectively. The SMR method exhibited a statistically significant reduction of 2.01 degrees compared to TSI ($P = 0.022$).

The average duration of TSI and SMR techniques was found to be 150.93 ± 33.58 seconds and 162.81 ± 37.07 seconds, respectively.

Notably, the SMR method demonstrated a longer duration by 11.88 seconds compared to the TSI method, and this difference was statistically significant ($P < 0.001$) (Table 1).

As depicted in Figure 3, the average ROM in flexion-extension and lateral bending was observed to be lower in the SMR group compared to the TSI group. Interestingly, this finding contradicts the difference in immobilization time, where TSI had a shorter duration compared to SMR.

4. Discussion

In this randomized crossover trial, we compared cervical spine movement between TSI and SMR techniques. The study's primary objective was to evaluate differences in the average ROM in flexion-extension, rotation, and lateral bending during immobilization using these two methods. Our findings revealed that SMR led to a significantly lower mean ROM in flexion-extension and lateral bending compared to TSI. However, no significant difference was observed in rotation. Additionally, as part of the secondary outcome assessment, we aimed to evaluate the time required for immobilization. The results indicated that the SMR method resulted in a more extended movement time than the traditional immobilization method, which was statistically significant.

However, the slight increase in time observed with SMR compared to TSI, averaging 11 seconds, was deemed not clinically significant within the context of real prehospital trauma care scenarios. The primary benchmarks in prehospital trauma care are response time (from EMS activation to the arrival of prehospital teams at the scene), ideally less than 10 minutes, and scene time (total duration of on-scene care), ideally less

Figure 2: **A:** Traditional spinal immobilization (TSI) that used long spinal board (left) **B:** Spinal motion restriction (SMR) that used scoop stretcher (right).

Table 1: Comparing three-dimensional range of motion (ROM) in the flexion-extension, rotation, and lateral bending of the cervical motion as well as immobilization time between traditional spinal immobilization (TSI) and spinal motion restriction (SMR)

Variables	TSI		SMR		P-value
	Mean ± SD	95% CI	Mean ± SD	95% CI	
Range of motion (degree)					
Flexion-extension	13.92 ± 4.97	12.22 - 15.63	10.74 ± 3.33	9.60 - 11.88	0.001
Rotation	13.86 ± 3.87	12.50 -15.16	14.05 ± 3.74	12.77 - 15.34	0.769
Lateral bending	16.09 ± 4.69	14.47 -17.70	14.07 ± 5.17	12.30 -15.85	0.022
Immobilization time (second)					
Mean ± SD	150.93 ± 33.58	-	162.81 ± 37.07	-	< 0.001

CI: confidence interval; SD: standard deviation.

than 10 minutes [31]. The marginal increase of 11 seconds, on average, did not impact the ability to meet these critical time guarantees in prehospital care.

The study findings indicated significant differences in cervical spine movement and the duration of immobilization between the two techniques under investigation. Specifically, SMR reduced flexion-extension and lateral bending, suggesting potential advantages in limiting specific types of movements. However, it is essential to consider the longer duration required for immobilization with this method. The precise role of spinal movement in contributing to the worsening of neurological injuries remains uncertain. This uncertainty poses challenges in drawing definitive conclusions about the clinical relevance of these findings [32]. Nevertheless, there is a consensus within the medical community that temporarily minimizing movement is a preferable approach to mitigate the risk of exacerbating injuries. Balancing the benefits of reduced motion with the practical considerations of application time is a critical factor in optimizing patient care, particularly in pre-hospital settings.

Our findings align with a prior investigation by Swartz EE et al. [23], which examined spinal immobilization techniques in healthy male volunteers. In that study, they employed TSI involving a LSB, a head immobilization pillow, a cervical collar, and SMR using only a cervical collar. They measured the peak ROM and cumulative integrated motion during loading, transportation, and unloading. Additionally, they assessed vital signs and pain levels. The results of that study revealed that TSI immobilization led to higher cumulative integrated motion and peak ROM in the horizontal plane when compared to SMR immobilization.

In contrast, a study conducted by Liengswangwong W. et al. sought to assess the effectiveness of various methods, including LSB, sked stretchers, and vacuum mattresses, for immobilizing the cervical spine during patient transportation [24]. The study's findings indicated that the predictive margins for immobilization, as observed with LSB, vacuum mattresses, and Sked stretchers, did not reveal clinically significant differences in cervical spine movement.

The practical application of these findings in pre-hospital settings involves a thoughtful and individualized approach. While SMR techniques may offer benefits in certain scenarios, providers must weigh these advantages against the potential drawbacks of longer immobilization times. This consideration emphasizes the need for ongoing training and education for emergency medical services personnel to make informed decisions that prioritize patient safety and well-being in the critical moments following a suspected spinal injury.[19] In the United States, a policy was implemented to train pre-hospital care providers, including paramedics and emergency medical technicians, in SMR techniques to replace the use of TSI and reduce the use of LSB [33].

For the statistically significant difference of ROM in flexion-extension and lateral bending in the study, we do not have the information about the angle that affects the neurological outcome. Thus, further research is needed to validate these

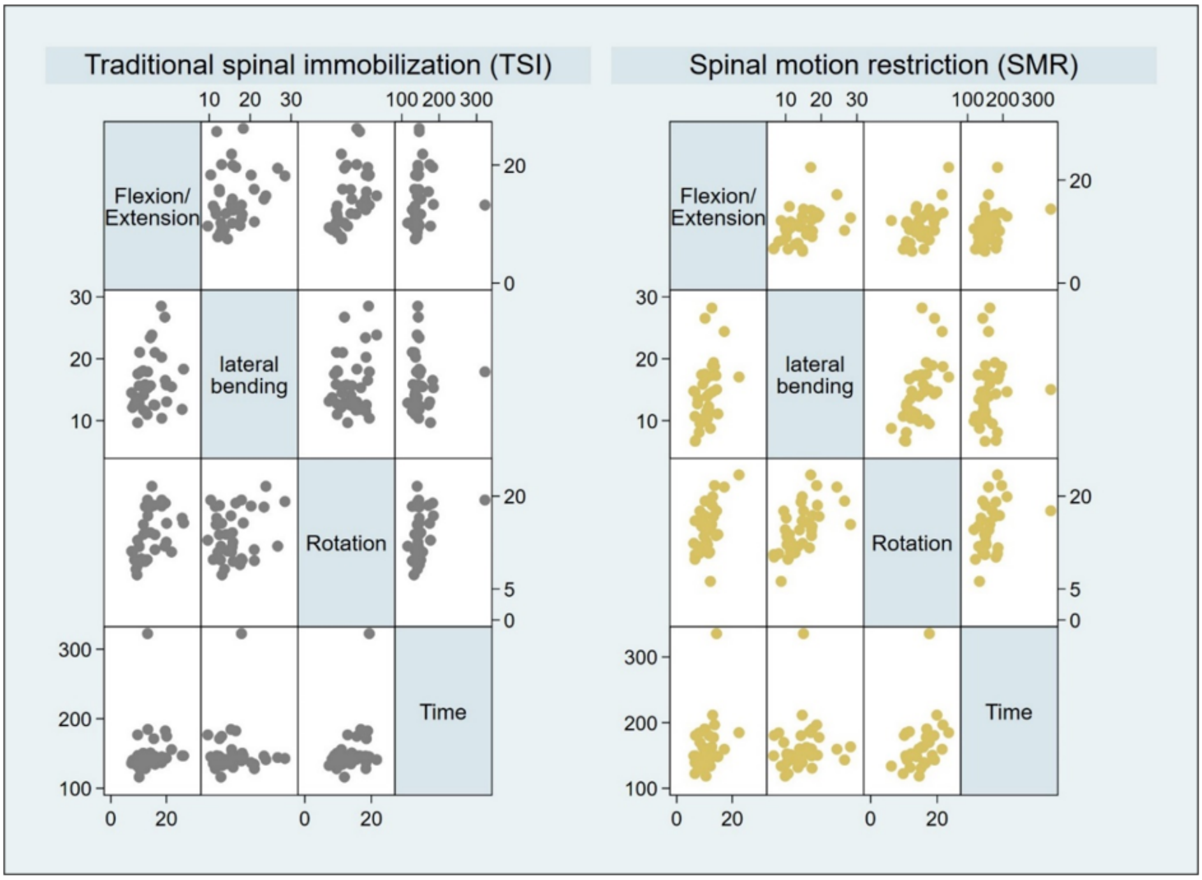

Figure 3: Scatter plot of Three-dimensional, Range of motion (ROM) in the flexion-extension, rotation, lateral bending of the cervical motion (degree) and time to immobilization.

findings and determine the long-term effects of SMR compared to TSI. Additionally, it is essential to consider individual patient factors, clinical circumstances, or real transportation situations by ambulance [34] when choosing the most appropriate method for cervical spine immobilization. Further investigation is warranted to validate these findings with actual trauma patients through randomized controlled trials. Additionally, there is a need to assess the long-term effects of SMR in comparison to TSI.

5. Limitations

This study had some limitations. First, the small sample size and excluding the females, which may reduce the statistical power, precision of the estimates, and generalizability of findings. Second, the limitations of generalizing the results from healthy volunteers to trauma patients, who may have different characteristics and responses to the interventions. Additionally, the study only measured cervical spine movement and did not assess other factors, such as patient comfort, that may be important in choosing an immobilization method. The lack of blinding of the participants and the researchers, which may introduce performance bias and measurement bias. The multiple comparisons of the outcomes, which may increase the risk of type I error or false positives. The last limitation is the nonappearance of supporting information for the specific angle of cervical spine movement within the potential affiliation of unfavorable neurological results.

6. Conclusions

In pre-hospital traumatic care, employing SMR via scoop stretcher demonstrated greater efficacy in limiting patient cervical spine movement compared to TSI using an LSB, with no clinically significant time disparities observed. However, it is essential to note that this study was conducted on healthy volunteers and research assistants. Therefore, further investigation involving actual trauma patients, clinical trials, and exploration of the long-term effects of SMR in contrast to TSI is recommended.

7. Declarations

7.1. Acknowledgments

College of Sports Science and Technology, Mahidol University, Thailand for use of the laboratory for data collection.

7.2. Conflict of interest

The authors declare that they have no competing interests.

7.3. Funding

This study was funded by Faculty of Medicine, Ramathibodi Hospital, Mahidol University.

7.4. Authors' contribution

All of the authors significantly contributed to the idea, planning, implementation, data collection, analysis, and interpretation of the study. The article's creation, revision, or critical evaluation involved input from all authors. All authors agreed on the journal to which the manuscript was submitted, granted their final approval of the version to be published, and agreed to take responsibility for every part of the work.

7.5. Ethical considerations

This study was approved by the Faculty of Medicine, Committee on Human Rights Related to Research Involving Human Subjects, Ramathibodi Hospital, Mahidol University on 29 November 2022 (IRB COA. MURA2022/688)

7.6. Availability of data and material

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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