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Prehospital Cervical Spine Motion: Immobilization Versus Spine Motion Restriction

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Abstract

Objective: This study aims to evaluate the efficacy of two different spinal immobilization techniques on cervical spine movement in a simulated prehospital ground transport setting. **Methods**: A counterbalanced crossover design was used to evaluate two different spinal immobilization techniques in a standardized environment. Twenty healthy male volunteers (age = 20.9 ± 2.2 yr) underwent ambulance transport from a simulated scene to a simulated emergency department setting in two separate conditions: utilizing traditional spinal immobilization (TSI) and spinal motion restriction (SMR). During both transport scenarios, participants underwent the same simulated scenario. The main outcome measures were cervical spine motion (cumulative integrated motion and peak range of motion), vital signs (heart rate, blood pressure, oxygen saturation), and self-reported pain. Vital signs and pain were collected at six consistent points throughout each scenario. **Results**: Participants experienced greater transverse plane cumulative integrated motion during TSI compared to SMR ($F_{1,57} = 4.05$; $P = 0.049$), and greater transverse peak range of motion during participant loading/unloading in TSI condition compared to SMR ($F_{1,57} = 17.32$; $P < 0.001$). Pain was reported by 40% of our participants during TSI compared to 25% of participants during SMR ($\chi^2 = 1.29$; $P = 0.453$). **Conclusions**: Spinal motion restriction controlled cervical motion at least as well as traditional spinal immobilization in a simulated prehospital ground transport setting. Given these results, along with well-documented potential complications of TSI in the literature, SMR is supported as an alternative to TSI. Future research should involve a true patient population. **Key words:** spine injury; spinal cord; trauma

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Introduction

Background

Historically, multiple medical disciplines have supported guidelines for healthcare providers that recommend using a long spineboard, headblocks, and cervical collar to achieve full spinal immobilization in patients with suspected spine injuries during extrication and transport (1–3). This method, referred to here as traditional spinal immobilization (TSI), was believed to limit spine motion and therefore protect patients from exacerbating a spine injury. More recently, emergency medical services (EMS) protocols in many states have evolved such that TSI using long spineboards and headblocks is no longer recommended for routine prehospital use (4, 5). Alternatively, patients are managed by a technique often referred to as Spinal Motion Restriction (SMR), whereby a patient is fitted with a cervical collar and secured flat on a standard ambulance cot. Long spineboards or scoop stretchers may still be used for extrication and patient movement on scene but patients are removed from these devices when transferred to the ambulance cot for transportation. The rationale for changing the protocol derives from evidence demonstrating potential patient complications from using long spineboards including increased pain (6), skin pressure wounds (6), and respiratory compromise (7), as well as operational considerations such as increased scene time (8), in conjunction with little evidence demonstrating improved patient outcomes by utilizing TSI. While the use of SMR is becoming more prevalent, there remains a notable lack of evidence supporting these protocol changes.

Indeed, two studies have questioned the long spineboard's effectiveness to even achieve immobilization (9, 10). Other research reported less capability of the spineboard to control spine motion compared to a vacuum mattress (11), scoop stretcher (12), and to a padded litter used for air transport (13). One study

compared TSI to SMR for lateral motion control (only) during simulated hospital transport in an ambulance (14) and reported superior motion control when subjects were secured to the stretcher mattress without a long spineboard. However, no research exists comparing TSI to SMR in limiting three-dimensional head and neck motion throughout the entire spine-injured patient's acute, pre-hospital management experience. Generating additional evidence to support these protocol changes is paramount to enhancing patient safety and adoption of emerging SMR protocols.

Therefore, our study's primary objective was to compare the difference in cervical spine motion during the prehospital immobilization and transport of a simulated patient between TSI (using a long spineboard, headblocks, and a cervical collar) and SMR (using a cervical collar only, and securing directly to the ambulance cot) to elucidate quantifiable evidence in response to increasing trends in protocol transitions from TSI to SMR. Secondary outcomes were measurements of vital sign changes and reported pain.

METHODS

Study Design and Setting

Our study utilized a counterbalanced, crossover design, conducted in a standardized setting. Transport was conducted using a current New Hampshire state-registered ambulance currently approved for patient use (2012 Chevrolet G4500 cutaway chassis on leaf springs with a 170″ module manufactured by PL Custom Emergency Vehicles, Manasquan, NJ). This study received approval from the University of New Hampshire's Institutional Review Board for the Protection of Human Subjects in Research.

Participants

A convenience sample of healthy, college-aged males volunteered to participate (n = 20, age = 20.9 ± 2.2 yr, height = 178.6 ± 7.6 cm, mass = 83.4 ± 12.6 kg). Participants were excluded from the study if they had a history of destabilizing cervical spine pathology, an acute or chronic respiratory condition, claustrophobia, or felt they would be unable to remain motionless and at rest for up to 60 continuous minutes. Females were not included in this study due to potential complications for motion sensor placement on the sternum.

Methods and Measurements

Participants reported to a large, multi-use indoor space of a northeastern United States university campus. Participants provided informed consent and completed a health history questionnaire prior to data collection. Age, height, and mass were measured and recorded for each participant. All participants were issued a standard cotton t-shirt to wear for data collection. An adjustable cervical collar (Laerdel Stifneck Select Collar, Wappingers Falls, NY) was fitted per manufacturer's instructions to each participant by a single investigator, who was a nationally certified and state licensed emergency medical technician (EMT). Two MyoMotion inertial measurement unit (IMU) sensors (Noraxon USA, Inc., Scottsdale, AZ) were employed to record motion for all conditions and trials. The MyoMotion IMU sensor system has a static accuracy of ±0.4°. Double-sided, hypoallergenic tape (Cover-Roll Stretch, BSN Medical Inc, Charlotte, NC) were used to secure one IMU sensor to the participant's head and a second IMU sensor to the participant's torso. The head IMU sensor was located at the forehead center at the brow line. After making a deep V-cut to the middle of the cotton t-shirt, the second IMU sensor was placed on the sternum 2.54 cm inferior to the base of the cervical collar. Placement of the paired IMU sensors on these two contiguous body segments measured cervical spine range of motion. The IMU sensors were calibrated within the MR3.6 software (Noraxon USA, Inc., Scottsdale, AZ) with the participant standing in the anatomical position with the cervical collar in place.

Two immobilization techniques were investigated in a counterbalanced order: TSI versus SMR. To begin each technique scenario, participants were asked to lie supine on a padded mat in the gymnasium. This was the simulated injury site. A research assistant (licensed athletic trainer) provided manual stabilization of the participant's head as the participant underwent each prescribed technique scenario. Both techniques involved: 1) transferring the participant with a lift-maneuver onto a lowered ambulance cot (Stryker PowerPro XT Model 6500, Stryker EMS Corporation, Portage, MI); 2) securing the participant to the cot, raising the cot, and pushing the cot to a waiting ambulance; 3) loading the cot into the ambulance; 4) driving the ambulance on a standardized 15-minute route over approximately 10.3 km; 5) unloading the cot from the ambulance; 6) pushing it into the simulated emergency department setting; and 7) transferring the participant onto a simulated hospital transport stretcher. The procedural differences between the TSI and SMR techniques during the transport scenario are described in Table 1.

Prior to trials, participants were given standard instructions to avoid assisting the providers or moving their head and neck, consistent with emergency protocols. The immobilization and transfer techniques were performed by licensed athletic trainers, and nationally registered and state licensed EMS providers (paramedics and emergency medical technicians (EMTs). All providers reviewed and practiced the immobilization and transfer procedures prior to data collection. The same investigator secured all participants to the long spineboard and cot with adjustable straps for both immobilization techniques. The same

Table 1. Differences in the spinal immobilization and spinal motion restriction techniques during the rescue scenario

Scenario Information		Technique	
Phase	Description	Spinal immobilization	Spinal motion restriction
1	Transfer participant from the ground onto an EMS cot	Secured to a rigid spineboard with head immobilizer blocks and adjustable Velcro® straps; 6–8 person lift onto a long spineboard	4–6 person lift using a scoop stretcher; stretcher removed after patient on cot
2	Securing participant to the cot and pushing the cot to a waiting ambulance	Patient and spineboard secured to the cot with adjustable buckle straps	Secured directly to the cot with adjustable buckle straps
3	Loading the cot into the ambulance	Same method for both techniques	
4	Transporting the participant in the ambulance on a standardized 15-min (10.3 km) route	Same route for both techniques	
5	Unloading the cot from the ambulance	Same method for both techniques	
6	Transporting participant from the ambulance to the simulated emergency department setting	Same method and route for both techniques	
7	Transferring the participant from the cot onto a simulated hospital stretcher	Log roll method	Sheet transfer method

Phases 1–3 and 5–7 are Period 1 (Loading/unloading), Phase 4 is Period 2 (Transport).

ambulance, cot, and immobilization equipment were utilized for all trials. The walking speed while transporting the stretcher to and from the ambulance was paced by the same investigator. Meticulous adherence to speed limits (ranging between 40.23–80.46 kph) was maintained for a consistent ambulance speed over the identical paved-road route during trials.

Outcomes

The MR3 software recorded spine motion during the entire trial from the IMU sensors in the sagittal, frontal and transverse planes at 100 Hz. During data collection, event markers were placed into the data to mark the start of each phase. Phases 1–3 and 5–7 of each trial were then organized for our analyses into a Loading/unloading period, with a Transportation period consisting only of phase 4 in order to differentiate motion occurring during the time participants were in the ambulance. Cumulative integrated motion and peak range of motion were generated for each trial. Cumulative integrated motion functions as the total resultant movement in each plane (i.e., area under the curve). Because this variable is influenced by the duration of a trial, the unit degree-seconds is used. Participants' heart rate, blood pressure, and oxygen saturation (measured by Zoll X Series cardiac monitor, Zoll Medical Corporation, Chelmsford, MA) and perceived pain using a standard 11-point numeric rating scale from 0 (no pain) to 10 (worst possible pain) were recorded at the following 8 time points: 1) baseline, 2) after transfer from the floor to the cot, 3) after loading the cot into the ambulance, 4) at 5-minute intervals during the ambulance transport route (for a total of 3 recordings), 5) upon arrival into the simulated emergency department setting, and 6) after transfer onto the simulated hospital stretcher.

Analysis

We performed *a priori* power calculations for sample size estimation. Effect sizes were calculated specifically for related variables of head movement from literature with methods closest to the proposed methods of this project. Effect sizes were calculated to be in the range of 0.04 to 0.28. The estimated sample size was calculated based on moderate to large effect statistics with an alpha level of 0.05 and power of 0.8. For a large effect, the sample size for the proposed project was estimated to be 23 participants.

We performed within-subjects repeated measures ANOVAs for each spine motion variable and vital sign (heart rate, systolic pressure, diastolic pressure, and oxygen saturation). The main effects of period (loading/unloading, and transport) and condition (TSI and SMR), as well as the period by condition interaction effect, were modeled for each analysis using random-intercepts general mixed linear models. Any participant reporting pain during one or more assessment points within a given scenario was categorized as "endorsed pain." The proportion between participants endorsing pain or not endorsing pain was evaluated using an exact method test of association. All analyses were performed in SAS 9.4 (SAS Institute, Inc., Cary, NC). The *a priori* significance level was set at $P < 0.05$.

Results

Participants experienced greater transverse plane cumulative integrated motion during TSI compared to SMR ($F_{1,57} = 4.05$; $P = 0.049$). We observed greater

TABLE 2. Descriptive (means and 95% confidence intervals) for traditional spinal immobilization (TSI) and spinal motion restriction (SMR) by period (loading/unloading, and transport) in each motion plane for cumulative integrated motion and peak range of motion

Variable	Traditional Spinal Immobilization		Spinal Motion Restriction	
	Loading/Unloading	Transport	Loading/Unloading	Transport
Cumulative integrated motion, degree-seconds				
Sagittal plane	5017.3 (3463.9,6570.7)	9489.3 (6765.2,12213.5)	3060.4 (2219.5,3901.4)	10683.0 (7617.8,13748.6)
Frontal plane	2151.0 (1697.4,2604.6)	4667.8 (3513.6,5821.9)	1109.1 (915.6,1302.5)	4532.5 (3620.8,5444.2)
Transverse plane	2257.7 (1777.4,2738.0)	3870.8 (2638.4,5103.3)	964.1 (771.7,1156.5)	3828.0 (2935.0,4721.0)
Peak range of motion, degrees				
Sagittal plane	16.5 (14.0,18.9)	15.0 (12.4,17.7)	15.5 (12.7,18.3)	13.9 (11.0,16.8)
Frontal plane	12.6 (10.9,14.2)	18.0 (16.3,19.8)	11.9 (9.6,14.1)	17.9 (16.6,19.2)
Transverse plane*	13.2 (11.5,14.9)	8.6 (7.2,10.0)	8.8 (6.9,10.7)	10.4 (8.7,12.0)

Significant interactions are identified only for those outcomes for which phase differences between immobilization techniques were observed (i.e. differences in loading/unloading between TSI and SMR, differences in transport between TSI and SMR).
*Significant interaction ($F_{1,57} = 17.32$; $P < 0.001$) such that peak transverse range of motion greater in TSI compared to SMR when loading/unloading participant.

transverse peak range of motion during participant loading/unloading in TSI compared to SMR ($F_{1,57} = 17.32$; $P < 0.001$), but there were no differences between TSI and SMR during participant transportation. No other differences were observed between TSI and SMR for sagittal and frontal plane cumulative integrated motion and peak range of motion ($P > 0.05$ for all). All descriptive data and main effect for technique and period for spine motion data are provided in Tables 2–4.

Pain was reported by 40% (8 of 20) of our participants during TSI; whereas, only 25% (5 of 20) of participants reported pain during SMR. These proportions of reported pain between TSI and SMR were not statistically different ($\chi^2 = 1.29$; $P = 0.453$). Descriptive and statistical results for vital signs are provided in Table 5.

TABLE 3. Descriptive (means and 95% confidence intervals) and statistical results (F ratio, *P* value, and Effect size) for traditional spinal immobilization (TSI) and spinal motion restriction (SMR) in each motion plane for cumulative integrated motion and peak range of motion*

Variable	TSI	SMR	F	*P*	ES
Cumulative integrated motion, degree-seconds					
Sagittal plane	7253.3 (5591.5,8915.2)	6871.8 (4916.7,8826.9)	0.38	0.543	0.07
Frontal plane	3409.4 (2691.1,4127.7)	2820.8 (2110.2,3531.4)	3.20	0.079	0.26
Transverse plane†	3064.3 (2381.4,3747.1)	2396.1 (1759.7,3032.4)	4.05	0.049	0.32
Peak range of motion, degrees					
Sagittal plane	15.7 (14.0,17.5)	14.7 (12.7,16.6)	2.04	0.159	0.18
Frontal plane	15.3 (13.9,16.7)	14.9 (13.3,16.5)	0.27	0.606	0.09
Transverse plane	10.9 (9.6,12.2)	9.6 (8.3,10.8)	3.25	0.077	0.34

*Only the main effect of technique findings are presented.
†Less transverse plane cumulative integrated motion during SMR compared to TSI.

TABLE 4. Descriptive (means and 95% confidence intervals) and statistical results (F ratio, *P* value, and Effect size) for loading/unloading and transport periods in each motion plane for cumulative integrated motion and peak range of motion*

Variable	Loading/unloading	Transport	F	*P*	ES
Cumulative integrated motion, degree-seconds					
Sagittal plane†	4038.9 (3138.7,4939.0)	10086.3 (8120.7,12051.8)	94.29	<0.001	1.35
Frontal plane†	1630.0 (1340.6,1919.5)	4600.1 (3898.3,5302.0)	81.60	<0.001	1.92
Transverse plane†	1610.9 (1287.2,1934.6)	3849.4 (3123.5,4575.4)	45.49	<0.001	1.36
Peak range of motion, degrees					
Sagittal plane‡	16.0 (14.2,17.8)	14.5 (12.6,16.3)	4.19	0.045	0.27
Frontal plane§	12.2 (10.9,13.5)	18.0 (16.9,19.0)	52.30	<0.001	1.56
Transverse plane‡	11.0 (9.6,12.4)	9.5 (8.4,10.6)	4.10	0.048	0.39

*Only the main effect of period is presented.
†Loading/unloading period produced less motion than the transport period.
‡Transport period produced lower peak range of motion compared to loading/unloading period
§Loading/unloading period produced lower peak range of motion compared to transport period

Table 5. Descriptive (means and 95% confidence intervals) and statistical results (t statistic, P value, and Effect size) for traditional spinal immobilization (TSI) and spinal motion restriction (SMR) for maximal changes in heart rate, systolic pressure, diastolic pressure, and oxygen saturation

Variable	TSI	SMR	t	P	ES
Heart rate (bpm)	4.9 (3.4,6.4)	3.8 (1.8,5.7)	1.21	0.242	0.32
Systolic pressure (mmHg)*	9.0 (2.4,15.6)	0.6 (−3.5,4.6)	2.14	0.046	0.74
Diastolic pressure (mmHg)	8.9 (5.1,12.6)	4.0 (1.4,6.5)	2.08	0.051	0.73
Oxygen saturation (SpO_2)	0.9 (0.4,1.3)	1.2 (0.7,1.7)	1.05	0.309	0.33

*There was a greater change in systolic pressure during TSI trials compared to SMR trials.

Discussion

Many practices in medicine, including traditional spinal immobilization, are widely accepted despite the lack of evidence demonstrating efficacy or improved outcome. It is increasingly being accepted that routine TSI practices should no longer serve as the default state for transport of trauma patients, as a very low percentage are even in need of spinal precautions. For example, a large retrospective cohort study in Australia reported only 0.2% (257/106,059) of potential spinal cord injured patients were confirmed as having a spinal cord injury at diagnosis (15). Combined with known adverse outcomes associated with long spineboards (4, 6, 7), and other recent research calling into question their efficacy for immobilization (9–14), our results further challenge the long-held belief that immobilizing a patient on a long spineboard is necessary for providing spinal precautions in the prehospital setting. Indeed, Dixon et al. (10) demonstrated controlled self-extrication from a car resulted in decreased cervical spine motion when compared to standard extrication techniques. Our study further complements these results, suggesting that partial self-immobilization via SMR may provide superior cervical spine motion control when compared to TSI. An awake, cooperative patient may be the best tool in limiting spinal motion.

To our knowledge, this is the first study to measure three-dimensional spine motion across all phases of a spine-injured patient, combining multiple transfers with transport in an ambulance. Trials were long in duration, with multiple providers and maneuvers involved in the process. We believe the time burden and intricate technical maneuvers necessary for TSI protocols may contribute to greater spine motion from the scene through hospital admission. Contrasted with SMR, fewer people and steps are necessary to scoop-stretch a participant, which may cause less spine motion (12). Furthermore, while a lift maneuver can be readily employed for transferring a patient onto a spineboard prior to transport, this will typically necessitate the use of a log-roll maneuver in the hospital setting to remove the device. Prior research using an injured cadaver-model characterized the motion experienced at the destabilized segment during a series of transfer maneuvers likely employed from the moment of injury up to the point of surgical intervention (16), showing traditional log-roll maneuvers contributing to greater displacement than a lift technique. Thus, while the log-roll employed at the completion of our trials certainly contributes to most differences found, it is a recommended and practical technique at this juncture and, therefore, a component of the TSI protocol.

While our primary objective was to explore potential differences in motion control during the entire prehospital experience, we organized phases of the process into two distinct periods so that we could ascertain how each protocol compares during transportation in the ambulance versus during the events that precede and follow (loading/unloading). The lack of a difference in motion control between TSI and SMR during ambulance transport is clinically meaningful since it has been generally assumed the spineboarded patient would experience less motion. Prior research similar to ours has compared motion control during simulated transport. Using a tilt-table to simulate positional orientation during air transport, Weber et al. (13) reported no differences in head motion between a padded litter and a long spineboard. While in a study measuring only lateral head motion, Wampler et al. (14) reported a stretcher mattress reduced lateral motion compared to a long spineboard. Furthermore, it is interesting that we also found main effect differences between the loading/unloading period and transport, regardless of condition. It is not surprising that there was greater cumulative integrated motion during transport, given this variable's influence by time and the time spent in the ambulance was greater than time spent before and after. However, peak frontal plane motion was greater during transport compared with loading/unloading, perhaps raising awareness of factors that might be considered to enhance motion control in light of the inertial influences imparted to the patient via vehicular transport during this time. For example, Tucker, Swartz, and Horner (17) reported differences in head and trunk accelerations experienced by healthy volunteers between various terrain and manufacturer of an intermediate emergency transport vehicle.

We sought to explore the effects of TSI and SMR on both the subjective (pain) and objective (vital

signs) patient experience. This was done to replicate previous research reporting adverse effects due to pain from patients being secured to a long spineboard for long time periods (6). While participants reported pain more often during TSI (40%) trials compared to SMR (25%) trials in our study, this proportion was not statistically different. Blood pressure appears to be higher during TSI, which may, or may not, be desirable dependent on a patient's condition. A larger and wider sample (e.g., elderly) may have resulted in larger differences in these measures. Regardless, we point out that the total time for our trials was approximately 30 minutes for TSI and 25 minutes for SMR. Incidentally, we find it important to also point out that the shorter time duration for SMR trials, of approximately 5 minutes, is desirable for decreasing on-scene time. Nevertheless, we recognize our trials may have been too short to elicit the pain and vital sign effects reported in previous retrospective reports. Considering our healthy participants were experiencing no pain at the start of data collection, it is noteworthy that these procedures resulted in pain in a relatively short time in otherwise healthy individuals.

We acknowledge certain limitations to our study. Our sample was small, and consisted of healthy, young adult male volunteers who were able to follow commands. The outcomes, namely pain and vital signs, may behave differently in injured patients, particularly in patients with altered mental status or distracting injuries. Future studies should address spine motion and outcomes in a diverse patient sample to better understand the patient experience between TSI and SMR. Due to the nature of the study we were unable to blind patient care providers or the ambulance operator to study condition. Finally, the amount of spine motion required to exacerbate injury remains unknown, making it difficult to draw clinical significance. In the meantime, it is generally agreed that less motion is desirable to reduce any risk of worsening the injury.

In conclusion, the long spineboard has been historically used to extricate and transport patients with suspected cervical spine injuries, but many jurisdictions have already moved toward spinal motion restriction protocols, with successful reduction in the use of spineboards reported (18). Our study provides evidence suggesting spinal motion restriction is at least similar, but perhaps superior, to spinal immobilization in reducing cervical spine movement during prehospital management. Future studies should look at the effect of SMR in clinical practice to further provide evidence for optimal immobilization strategies.

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