Biomechanical Motion Analysis of Cervical and Thoracolumbar Spine During Ambulance Transport: A Healthy Volunteer Study

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Abstract

Background: Recent evidence suggests that long spine board (LSB) may do little to manage spinal motion, and pose increased risk. This project sought to measure cervical and thoracolumbar motion during ambulance transport. The hypothesis was transport on a mattress with the head elevated without the LSB would allow less spinal movement than transport on an LSB.

Methods: A randomized healthy volunteer crossover trial measured spinal motion using biometric sensors. Positions analyzed included 0 and 10° on LSB. Stretcher alone with head elevated to 10°, 30°, 45° and 60°, with and without head blocks. Simulated ambulance transport was on city streets at or below posted speed limits.

Results: Nine subjects were included, with 66% being male. For cervical movement, there was no difference in axial, flexion/extension, or rotation (0.2 ± 0.1 mm vs. 0.2 ± 0.1 mm, 24 ± 12 mm vs. 22 ± 10 mm, and $5.1 \pm 19°$ vs. $5.8 \pm 20°$, respectively). There were significant differences in lateral (3.7 ± 7 mm LSB vs. 2.0 ± 5 mm no LSB) movement and volumetric movement of the head (120 ± 172 mm^3 LSB vs. 77 ± 86 mm^3 no LSB). Positions allowing the lowest mean cervical volume of head movement were bed elevated to 30° and 45° with head blocks, (20 ± 22 mm^3 and 12 ± 6 mm^3, respectively). For thoracolumbar movement, there was no statistical difference in three-dimensional volumetric movement of the thoracolumbar spine (2 ± 0.6 mm^3 LSB vs. 4.7 ± 5 mm^3 no LSB).

Conclusion: Spinal motion was small in all groups. The stretcher mattress without LSB allowed less cervical motion than the LSB. Subjects secured to a stretcher mattress with head of the bed elevated to 30° had the least spinal movement.

Keywords: Spinal motion restriction; Prehospital medicine; EMS transport

Introduction

Since J. D. Farrington first formally described the long spine board (LSB) in "Death in a Ditch" [1], emergency medical services (EMS) providers have used this medical device during extrication and transport of trauma victims. The immobilization process is intended to hold the head in line with the torso to prevent secondary injury to the neural tissue that would normally be protected by the healthy spinal column. Historically, EMS providers have used an LSB during treatment and transport of any patient at risk for cervical spine injury. Despite the ubiquitous use of the LSB, there is a paucity of data documenting its safety and efficacy.

Complications related to the use of the LSB as an immobilization device may lie in its design. The LSB consists of a smooth, hard, flat surface with a low coefficient of friction. Specifically, the flat design offers no support for the natural lordotic curvatures of the human spine, likely a contributor to the discomfort and pain [2] patients experience, particularly during protracted transports from the field or between medical facilities.

In addition to pain, LSB utilization has been associated with increased anxiety following a traumatic event, cutaneous pressure ulceration [2], elevated intracranial pressure [3] and increased difficulty with airway management [4]. Likewise, use of the LSB may lead to unnecessary diagnostic imaging, as providers may have difficulty distinguishing if pain results from initial traumatic injury or from the patient being secured to the LSB for an extended period of time [5]. There is also a body of data that indicates LSB use in some trauma patients may actually be harmful [6, 7].

In contrast, modern ambulance stretchers have a padded mattress designed to conform to a patient's anatomy. The stretcher mattress is designed for comfort, with a higher coefficient of friction, and demonstrated superiority in reducing patient movement over the LSB [8]. To date, there have been

no randomized controlled trials of spinal immobilization strategies for the transport of trauma patients [9].

Furthermore, there is little evidence to support the optimal elevation levels for the head of the stretcher during prehospital transport. The contemporary critical care and neurosurgery literature suggest that intensive care patients suffering from traumatic brain injury should have the head of the hospital bed elevated to 30° as a therapeutic adjunct to control intracranial pressure and to minimize complications of aspiration [3, 10]. However, a Cochrane review in 2017 called into question the literature supporting this standard practice and recommended clinical outcome trials to be conducted to validate this practice [11].

A previous publication looking at the lateral motion on and off the LSB on an EMS stretcher [8] used analog measurement to determine lateral motion. Current technology allows for the accurate three-dimensional (3D) biomechanical analysis of complex human movement. In light of the paucity of evidence supporting the use of the LSB as an immobilization device for the management and transport of the potentially spinally injured patient [12], this study was developed with the following goals: to evaluate the biomechanical motion of the spine on the padded EMS stretcher compared to the LSB and to evaluate the biomechanical impact of the elevation of the head of the EMS stretched on spinal movement during transport.

Materials and Methods

Study design

This was a randomized 10-sequence crossover biomechanical analysis of nine healthy volunteers. Body movement was recorded while each participant was transported by ambulance in various spinal immobilization conditions. Comparisons included participant's body movements (cervical, torso, thoracolumbar and pelvic) while immobilized on LSB with cervical collar (c-collar) and head blocks to body movement when placed directly on a stretcher alone both with and without c-collar and head blocks, in different head of stretcher elevations.

Instrumentation

Each participant underwent full informed consent, and their height and weight measurements were taken. Participants were fitted into full bodysuits with integrated Xsens (Xsens North America Inc., Culver City, CA) motion analysis technology, including 17 accelerometers which were secured to the following anatomical areas: forehead (via headband), neck, upper chest, abdomen, waist, thighs, calves, ankles, arms, forearms and hands (Fig. 1). Accelerometers were calibrated against the anatomical position. Inertial sensors facilitated the accurate kinematic measurement, using 17 wireless motion trackers for full-body human motion measurements. The system utilized the following four steps to estimate 3D joint angles: 1) definition of segment anatomical frame axes and segment lengths; 2) sensor to segment anatomical frame alignment; 3) relation of segment with global frame and 4) relation of two adjacent seg-
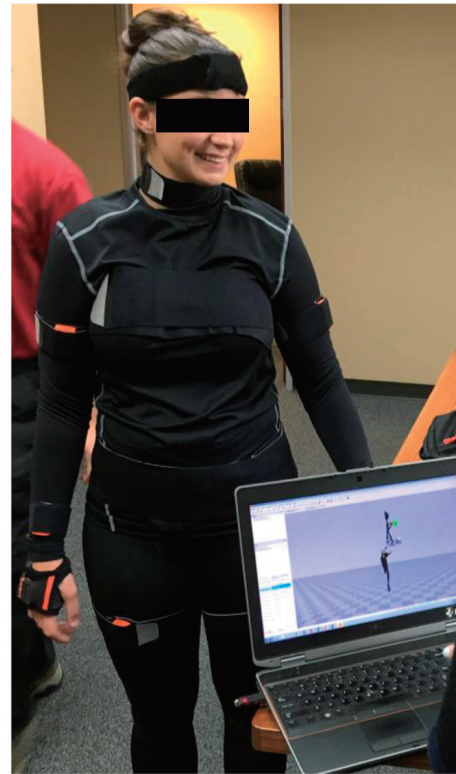

Figure 1. Model of the system used for measurement (including 16 accelerometers that communicate wirelessly), and the laptop interface.

ments. Body position and force vector data were continuously streamed at a rate of 50 Hz to a laptop computer running the manufacturer software.

Participant vital signs, including heart rate, blood pressure, blood oxygen saturation, respiratory rate and electrocardiogram, were monitored throughout each transport using a cardiac monitor with vital sign capability.

Transport conditions

A type III ambulance and a Stryker Power-PRO XT Ambulance Cot were used during the study. The driver was a professional paramedic and was blinded (closed partition) to randomized participant positioning. Transport time as 8 ± 1.5 min. Transport positions included: supine with the LSB at 0°, and supine with the LSB tilted head up to 10°, both with c-collar and foam head blocks (Fig. 2a). Transport conditions without the LSB included: supine with head of stretcher elevated 10°, 30° (Fig. 2b and c), 45° and 60°. Each head of stretcher position without the LSB was tested with and without rigid c-collar and lightweight foam head blocks. When c-collar and head blocks were used, they were secured to the stretcher with medical tape.

Once the participant was secured in the appropriate position according to the randomization scheme, data collection was initialized, and the driver drove a predetermined route on city streets. The route included five right turns, four left turns, two looping turns and two speed bumps.

Figure 2. (a) An example of a subject secured to a long spine board on the EMS stretcher with the head of the bed elevated to 10°. (b) Example of a subject secured to the stretcher with cerical collar without head blocks with the head of the bed elevated to 30°. (c) Example of a subject secured to the stretcher with cerical collar and head blocks with the head of the bed elevated to 30°.

Data collection and analysis

Motion data were abstracted from the proprietary software into spread sheets, and the data were transferred to an independent analysis service (Guidance Engineering, Seattle, WA) for analysis. Engineers were blinded to the study hypothesis.

For measurement of cervical motion, the motion of the head accelerometer device was compared only to the torso device; the torso was virtually anchored, and motion of the head was relative to a stationary torso. Likewise, for the thoracolumbar motion, the torso was virtually anchored, and the pelvic device motion was utilized. Volumetric motion was defined as the overall amount of space that one of the accelerometer devices occupied as a function of the thoracic accelerometer device.

Descriptive statistics were used for demographic and ordinal data; t-test was used to infer differences between transport positions; Chi-square was used for categorical data. In all cases statistical significance was defined as a P-value less than 0.05.

Results

Nine participants volunteered for this study, mean age was 36 years (95% confidence interval (CI): 27 - 45 years), mean body mass index (BMI) was 25 (95% CI: 23.1 - 28.1) and 66% were males. For cervical movement in the supine patient, there was no difference in axial, flexion/extension or rotation (0.2 ± 0.1 mm vs. 0.2 ± 0.1 mm, 24 ± 12 mm vs. 22 ± 10 mm and $5.1 \pm 19°$ vs. $5.8 \pm 20°$, respectively) when comparing LSB versus stretcher. There were significant differences in lateral (3.7 ± 7 mm LSB vs. 2.0 ± 5 mm no LSB) movement and volumetric movement of the head (120 ± 172 mm^3 LSB vs. 77 ± 86 mm^3 no LSB).

Positions allowing the lowest mean cervical volume of head movement were head of stretcher elevated to 30° and 45° with head blocks (20 ± 22 mm^3 and 12 ± 6 mm^3, respectively) (Fig. 3).

For thoracolumbar movement, there was no statistical difference in 3D volumetric movement of the thoracolumbar spine (2 ± 0.6 mm^3 LSB vs. 4.7 ± 5 mm^3 no LSB) (Fig. 4).

For vital signs monitoring, the mean blood pressures and heart rates are described in Table 1. There were no differences in vital signs to include pain level when comparing to the supine patient on LSB versus stretcher.

Discussion

This study precisely measures movement at the level of the head compared to the torso during ambulance transport with and without LSB and with the head of the stretcher elevated to various positions. By measuring the relative movement of the head (i.e. cervical motion), and movement of the hip (i.e. thoracolumbar), as compared to the torso during ambulance transport of healthy volunteers, the effect of spinal immobilization with the LSB was evaluated. In all scenarios, the participants had greater volumetric motion on the LSB than they did on the stretcher mattress alone.
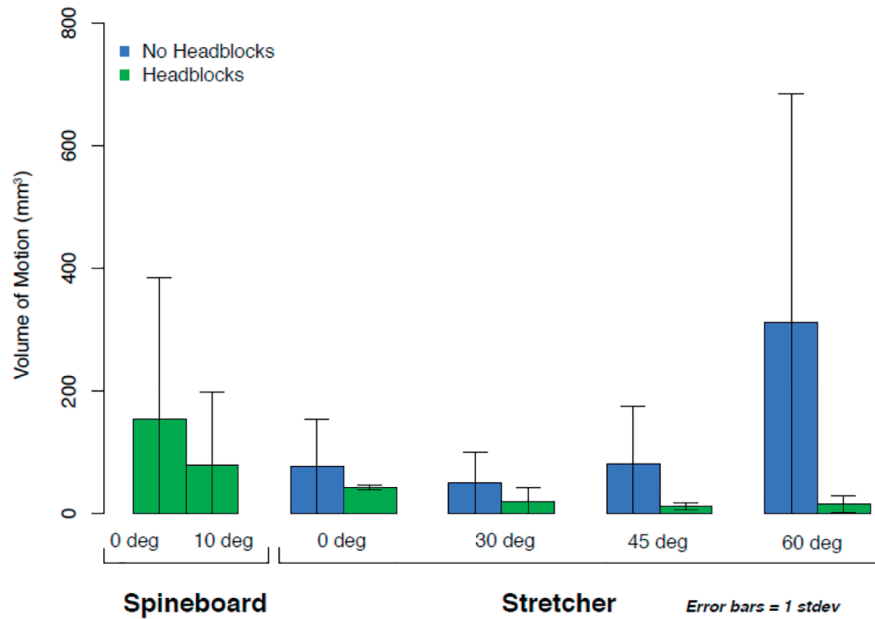
Figure 3. Bar graph with error bars of the total volumetric motion of the head relative to the torso. All subjects were fitted with a cervical collar during transport. All subjects on long spine board were also fitted with head blocks secured to the long spine board. Stretcher subjects were transported either with or without head blocks, and all transports were 8 min in duration.

Using the same biometric measurement technology and similar supine transport conditions, Thezard et al demonstrated reduced angular displacement and increased linear displacement in the supine patient on an LSB with c-collar and head blocks as compared to the supine patient with c-collar alone [13]. These data are consistent with observations in this paper, but with the inclusion of head blocks motion was less without the LSB. Furthermore, with the head of bed elevation motion was further reduced in the 30 - 45° range.

Based on our results, the head of stretcher elevated to 30° may be the optimal position to minimize movement. We speculate that this may be because the 30° angle still allows
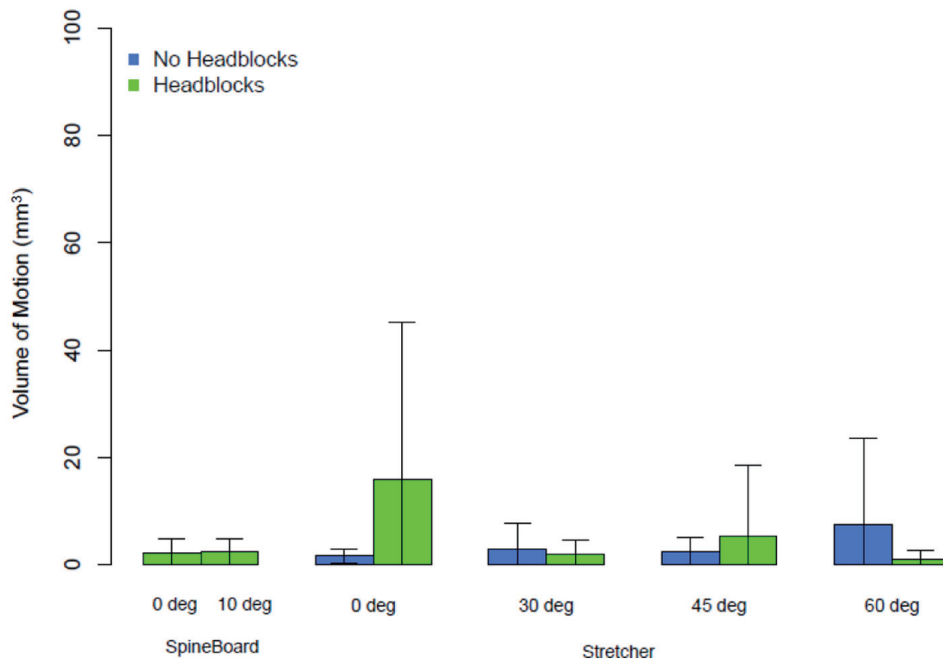

Figure 4. Bar graph with error bars of the total volumetric motion of the upper 10% of the thigh relative to the torso, all transports were 8 min in duration.

Table 1. Changes in Vital Signs

	Mean	SD	n	Maximum change	Minimum change
Long spine board					
Flat					
SPB	5.9	11.9	8.0	27	0
HR	1.3	6.6	9.0	14	0
Pain	0.2	1.1	9.0	3	0
10° HOBE					
SPB	0.6	13.2	9.0	26	2
HR	-0.3	8.6	9.0	7	3
Pain	0.4	0.5	9.0	1	0
Stretcher mattress without head blocks					
10° HOBE					
SPB	-3.2	9.9	9.0	17	2
HR	-4.0	11.0	9.0	10	3
Pain	0.0	0.0	9.0	0	0
30° HOBE					
SPB	-6.7	9.3	9.0	25	1
HR	-5.0	10.4	9.0	8	2
Pain	0.0	0.0	9.0	0	0
45° HOBE					
SPB	-0.9	11.5	9.0	18	0
HR	-5.3	10.3	9.0	22	2
Pain	0.0	0.0	9.0	0	0
60° HOBE					
SPB	3.9	9.0	9.0	17	0
HR	-0.7	4.9	9.0	10	0
Pain	0.0	0.0	9.0	0	0
Stretcher mattress and head blocks					
10° HOBE					
SPB	1.1	11.1	9.0	14	0
HR	0.9	13.4	9.0	27	2
Pain	0.4	0.7	9.0	2	0
30° HOBE					
SPB	-2.1	5.9	9.0	11	0
HR	-6.8	13.1	9.0	35	1
Pain	0.1	0.3	9.0	1	0
45° HOBE					
SPB	1.2	8.4	9.0	16	2
HR	-3.8	9.1	9.0	26	1
Pain	0.0	0.0	9.0	0	0
60° HOBE					
SPB	6.9	17.2	9.0	34	1
HR	1.0	7.5	9.0	14	1
Pain	0.1	0.3	9.0	1	0

Pain on a 1 to 10 scale. HOBE: head of bed elevation; SPB: change in systolic blood pressure (mm Hg); HR: change in heart rate (pulses per minute); SD: standard deviation.

significant weight to be distributed along the stretcher mattress. Even during hard ambulance breaking events, the elevation preserves a more normal body position and hemodynamics of blood flow into, and out of, the head [14]. In addition, although not specifically shown in this study, this position would be expected to be more comfortable for most patients when compared to the LSB. While there is concern that sitting the potentially spine injured patient too upright may induce significant downward force on the spine and exacerbate existing injuries, it is interesting to note that small movements are detected in all positions except for head of stretcher elevated to 60°, which had much higher movement. While there is no significant information on the tolerable amount of safe cervical motion, it is likely that some cervical motion is tolerable [8, 15]. Our results demonstrate that the LSB had more movement of the neck to the torso when compared to a modern ambulance stretcher. The clinical importance of this finding is unclear as our study cohort did not have spinal column injury. The LSB may still have utility as an extrication tool to carry patients short distances by foot from the exact site of the injury.

Limitations

This is a nonclinical, healthy volunteer study of uninjured participants; therefore, participants did not self-splint or experience significant pain upon movement unlike a patient who has experienced a traumatic injury. Likewise, it is unclear if spinal column injuries would produce more volumetric movement during transport, especially those with mechanically unstable fracture patterns. The sample size is small, but the frequency of data point capture (50 Hz) resulted in a very large dataset, with each of nine patients undergoing an average of 8-min transport per position.

Conclusion

Based upon this study's findings, we submit that the optimal transport modality is on stretcher with head blocks and head of stretcher elevated to 30°.

Acknowledgments

None to declare.

Financial Disclosure

Conflict of Interest

All authors report no conflict of interest.

Informed Consent

Each participant underwent full informed consent.

Author Contributions

DW: study design and manuscript preparation. DW, RMS, RSum, RSch, TL, CC, MS, CK, BE and LR: data management.

Data Availability

The authors declare that data supporting the findings of this study are available within the article.

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