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The Efficacy of Head Immobilization Techniques During Simulated Vehicle Motion

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Study Design. Laboratory experiment.

Objective. To compare the efficacy of different head immobilization techniques during motion simulating ambulance transport.

Background. A significant number of neurologic injuries associated with cervical spine fractures arise or are aggravated during emergency extrication or patient transport. Previous studies have not addressed the effect of head immobilization on the passive motion that could occur across the neck during transport.

Methods. Three different head-immobilization methods were compared in six healthy young adults by using a computer-controlled moving platform to simulate the swaying and jarring movements that can occur during ambulance transport. In all tests, the trunk was secured by means of a commonly used "criss-cross" strapping technique. Efficacy of head immobilization was evaluated using measures of head motion and neck rotation.

Results. None of the three immobilization techniques was successful in eliminating head motion or neck rotation. Movement of the trunk contributed substantially to the lateral bending that occurred across the neck. A new product involving the placement of wedges underneath the head provided some small, but statistically significant improvements in fixation of the head to the fracture board; however, there was no improvement in terms of the relative motion occurring across the neck.

Conclusions. Somewhat improved fixation of the head to the fracture board can be achieved by placing wedges under the head; however, the benefits of any fixation method, in terms of cervical spine immobilization, are likely to be limited unless the motion of the trunk is also controlled effectively. Future research and development should address techniques to better control head and trunk motion. [Key words: ambulance, head, immobilization, spine, transport] **Spine 1999;24:1839–1844**

Historically, it has been reported that up to 25% of cervical spine injuries arise or are aggravated during emergency patient transport,[4,11] and that 40% of these injuries result in neurologic deficit.[12] Cervical spine immobilization techniques have been developed to help prevent movement of the head, thus minimizing the risk of incurring or exacerbating spinal injury during patient transport. Determination of the efficacy of the numerous immobilization methods typically has focused on the amount of movement that is possible in different planes under static loading conditions.[3,8–10,12,13] For example, individuals are instructed to exert voluntary head movements in a specific direction to determine the maximum possible range of motion while fitted with a specific immobilization device. Such static measures are evaluated using radiographic and/or goniometric techniques. For cervical orthoses, where one principal objective is to restrict the range of voluntary motion,[5] such measures are likely very useful. However, such static measures of efficacy are unlikely to provide information about the performance of emergency immobilization techniques when used on unconscious patients during dynamic movement conditions associated with patient transport.

In the current study, the authors specifically were interested in comparing the efficacy of different head-immobilization techniques during ambulance transport. To achieve this, they characterized the extent of immobilization achieved during vehicle motion simulated using a computer-controlled moving platform. Three different techniques to secure the head to the fracture board were evaluated. Immobilization efficacy was determined by measuring relative motion across the neck, as well as the motion of the head itself (with respect to the fracture board). The influence of exposure time (*i. e.*, the duration of the transport) on the efficacy of head immobilization also was assessed. It was hypothesized that a new technique involving the placement of styrofoam wedges under the head would provide improved head immobilization, compared with two other commonly used methods.

Methods

Study Participants. Six volunteers (three men, three women) were tested. The average age was 25 years (range, 22–28 years), the average height was 168 cm (range, 163–172 cm), and the average weight was 69 kg (range, 48–84 kg). By way of comparison, 178 patients with spinal column or cord injuries from 1994 to 1997 at Sunnybrook Health Science Centre had the following characteristics: 64% were men, the median age was 31 years, median height was 170.5 cm, and median weight was 75.6 kg. Thus, the subject pool in the current study provides a representative sample of this population. All volunteers signed an informed consent form before participation in the study. The protocol was approved by the local ethics committee.

Movement Simulation. Vehicle motion was simulated using a computer-controlled moving platform capable of moving in the horizontal plane. The platform motion, which was the same for all

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trials, was controlled to mimic the lateral vehicle accelerations that occur as a result of turning corners and changing lanes, as well as the swaying and sudden jerking induced by irregularities in the road surface. The authors elected to focus on lateral vehicle motion after pilot tests indicated that fore-aft acceleration (*e. g.*, caused by vehicle starts and stops) had relatively little effect on the head motion of a patient lying parallel to the fore-aft vehicle axis.

The platform motion featured a band-limited random (Gaussian) waveform, 2 minutes in duration. The frequency content ranged from 0.3 to 3 Hz, and the acceleration power spectrum was flat over this frequency range. The maximum and root mean square accelerations were 1.7 and 0.5 m/sec^2, respectively. The frequency and amplitude of the movement were selected to approximate the motion recorded in studies evaluating vibration in moving vehicles.[7] The frequency range contained the resonant frequency (1.5 Hz) of the unconstrained head, determined during pilot studies. The movement was sufficiently vigorous to cause an unconstrained lying volunteer to slide 0.5 m horizontally across the floor surface. It should be noted that the intent was to simulate the sudden jarring movements that are most likely to cause loosening of the immobilization systems. There was no attempt, in the current study, to simulate the large low-frequency accelerations that can arise when driving around a bend in the road.

Experimental Measures. Quantification of head and body movement was achieved using four high-speed shuttered cameras (60 frames/second, shutter speed 1/500 sec) and a video-based motion analysis system (Peak Performance, Inc., Englewood, CO). This system allowed the three-dimensional positions of reflective markers placed on the volunteer to be determined within a margin of error of ± 5 mm. The worst-case angular error resulting from marker error, in the calibrated space in this study, was ± 0.5°. Reflective markers were placed on the forehead, chin, zygomatic arches, distal clavicles, manubrium, and xiphoid process (Figure 1A). These sites were selected because they allowed for quantification of head motion relative to both fracture board and trunk, while providing a secure bony site for adhesion of the markers.

Volunteers also were instrumented with surface electromyographic electrodes on the trapezius and sternocleidomastoid muscles. Electromyographic measures were used to confirm that volunteers remained relaxed throughout the trials (to simulate a state of unconsciousness).

Methods of Immobilization. Each volunteer lay on a fracture board, which was fixed securely to the moving platform. The fracture board was made of wood (42 cm wide × 186 cm long), with two runners (120 cm long) on the underside of the board running parallel and centered 20 cm apart. The surface of the board was smooth (glossy varnish).

The method of securing the volunteer to the fracture board was determined by a consulting ambulance instructor, who selected the strapping method most commonly used in the authors' geographic region. The first three straps were placed over the volunteer, perpendicular to the longitudinal axis of the body. They were located below the knee, above the knee, and at the waist. Two additional straps crossed the chest diagonally, starting above the shoulder and crossing to the opposite waist (Figure 2). The feet and arms were secured with cotton slings to avoid excessive motion. To ensure that the straps did not impair respiration,[2] the authors adopted a common strategy similar to that used by Mazolewski and Manix;[10] the straps were applied snugly, but not so tight as to cause discomfort (unlike Mazolewski and Manix, however, the current authors did not apply a strap under the axilla). It was determined that an ability to insert two fingers between the strap and the volunteer provided a consistent method of ensuring similar body strap tension. Each volunteer was fitted with an appropriately sized neck brace (Stiffneck, California Medical Products, Long Beach, CA). Neck braces were used in all trials by all volunteers. Three methods of securing the head to the fracture board were evaluated: 1) rolled towels, 2) "Headbed II" (California Medical Products; Long Beach, CA), and 3) styrofoam wedges. The details of the application of each technique are provided below.

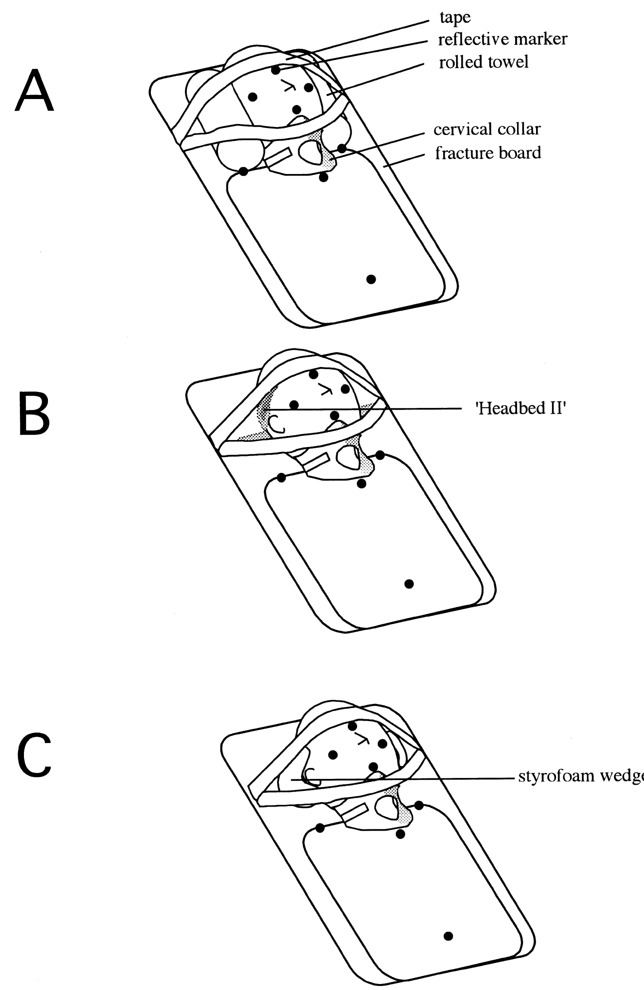

Figure 1. Different methods of securing the head to the fracture board. **A,** Towel method. **B,** Headbed II. **C,** Styrofoam wedges. Note that, in all cases, study participants wore a "Stiffneck" cervical collar. The reflective markers are placed on specific anatomic landmarks and are used, after digitization, to provide measures of head and trunk motion.

Towels were rolled up to form a 25-cm–long cylinder, which was approximately 13 cm in diameter. The rolls were placed on either side of the head, and two strands of tape (each 6 cm wide) were applied, one across the forehead and one under the chin; both pieces of tape were secured to the fracture board at approximately ear level (Figure 1A). This technique of immobilization commonly is used during emergency patient transport.

The Headbed II (California Medical Products) was applied as detailed in the instructions provided by the manufacturer.

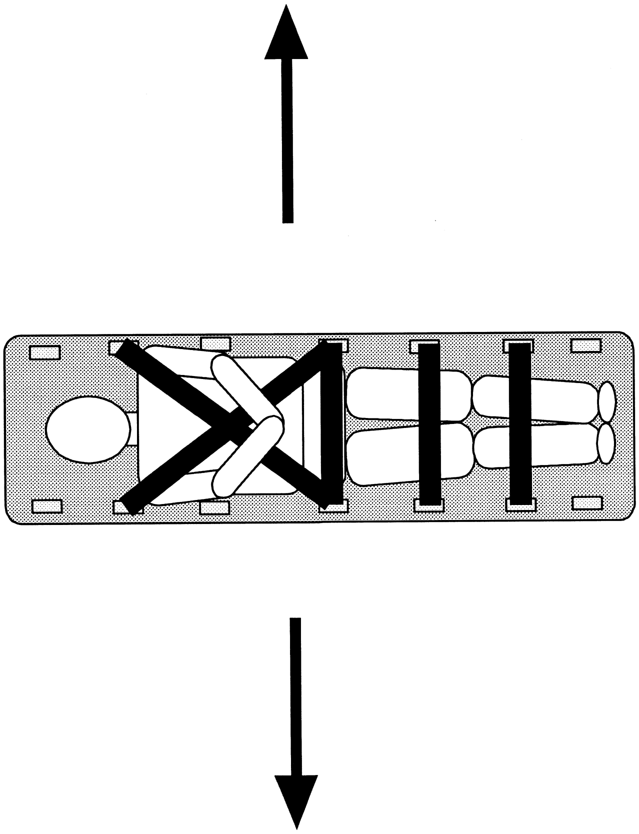

Figure 2. Method of strapping the body to the fracture board. The individual and board are shown as they are positioned on the moving platform. The arrows indicate the direction of imposed platform movement.

The Headbed II features a butterfly-shaped piece of cardboard, with a small styrofoam pad in the center to support the head. The bottom flaps of the Headbed adhere to the fracture board, and the top flaps wrap around the sides of the head and are connected with a strap across the forehead. As described above, tape was applied across the chin and forehead and secured to the fracture board at the ear level (Figure 1B).

The wedges (Manus Pharmaceutical, Inc., Mississauga, Ontario) represent a new technique in which L-shaped styrofoam wedges, contoured to fit behind the ear, are secured to the board on either side of the head. The longer portion of the L-shape runs anteroposteriorly from occipital to temporal regions of the skull, and the shorter portion contours under the ear to approximately the bottom of the ear (Figure 1C). The wedges were applied with double-sided adhesive tape which was located in a 5 cm × 5 cm space between two ridges on the underside of the wedge. The wedges were slid into position, and the two ridges were compressed by pushing downward on the wedges, causing the double-sided tape to adhere to the fracture board. Again, as described above, tape was applied across the chin and forehead (Figure 1C).

Protocol. Five of the six volunteers were tested using each of the three different methods of head immobilization: 1) towels, 2) wedges, and 3) Headbed (the first volunteer was tested with only the first two methods). The order of the different methods of immobilization was randomized across volunteers. Volunteers were instructed to lie quietly on the fracture board during all trials to simulate vehicle-induced movement consistent with an unconscious state. (Although it has been reported, anecdotally, that neck extensor spasm may occur during cervical dislocation or fracture, the current authors' protocol was intended to simulate the worst-case scenario, where the neck muscles provide no active stabilization).

Three volunteers were tested for approximately 8 minutes for each immobilization technique. For the three other volunteers, the duration of platform motion was extended to approximately 14 minutes, to simulate longer ambulance trips. Each 8-minute test comprised four consecutive exposures to the 2-minute random waveform described earlier; each 14-minute test comprised seven consecutive exposures to the 2-minute waveform. Repeated exposure to the same waveform allowed responses to identical intervals of platform motion to be compared across different stages of the trial.

Data Analysis. Quantification of the three-dimensional motion of the reflective markers was performed over a 15-second interval of platform motion: 1) at the beginning of the trial, and 2) after 6 minutes of platform motion. In addition, the three volunteers who were tested for longer durations were evaluated over a 15-second interval of platform motion near the end of the test (12 minutes after the commencement). Multiple measurement times were chosen to allow assessment of the ability to maintain immobilization of the head. Note that the platform motion was identical during each 15-second interval analyzed.

Absolute motion of the head itself (defined with respect to the fracture board) and relative motion across the neck (head motion relative to the trunk) were quantified in terms of axial rotation and lateral bending (adduction/abduction), resulting in a total of four primary measures (Figure 3). Measures of flexion–extension of the neck also were quantified; however, the absence of significant motion in this direction precluded further analysis. For each of the four primary measures, the peak-to-peak range and root mean square amplitude were determined. Repeated measures analysis of variance was conducted to determine the differences between immobilization techniques and the influence of time of exposure (*i. e.,* commencement of trial *versus* 6 minutes of exposure). In cases where the analysis of variance indicated significant differences caused by the immobilization technique, the means for the three techniques were compared with each other using *post hoc* multiple comparisons. Paired t tests were performed to determine differences between absolute measures (motion of head with respect to fracture board) and relative measures (motion of head with respect to trunk). In all cases, a probability level of 0.05 was used to define statistical significance.

■ Results

Figure 4 provides a summary of the average peak-to-peak range of motion determined for each of the four measures of head motion. Results are presented only for the peak-to-peak range of motion, because the analysis of the root mean square amplitude provided equivalent findings.

For all three immobilization techniques, there was substantial head motion, with average peak-to-peak range of axial rotation and lateral bending varying from 4 to 8 degrees, depending on the specific measure. The range of lateral bending was significantly larger when this motion was referenced to the trunk (relative neck rotation) rather than to the fracture board (absolute motion of the head itself) (average of 7.8° *versus* 4.0°, respectively; $P < 0.001$; Figure

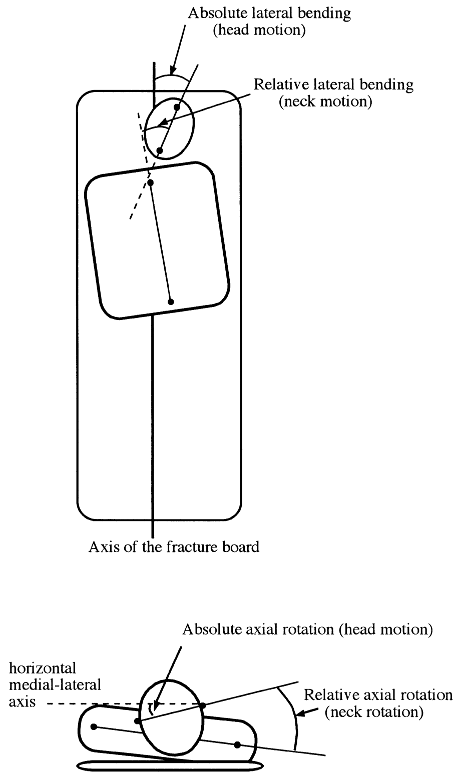

Figure 3. Schematic representation of the four measures of head motion computed for this study.

4A). This indicates that the motion of the trunk was a significant contributor to the amount of relative lateral bending movement occurring across the neck. Trunk motion did not appear to affect the axial rotation measures, however, as there was an average difference of only 0.7° between absolute and relative axial rotation.

The method of immobilization had a statistically significant effect on the amount of absolute head motion. Specifically, the styrofoam wedges led to consistently lower ranges of motion for absolute axial rotation ($P = 0.0004$) and absolute lateral bending ($P = 0.016$) than the Headbed (Figure 4B), although the average differences were small in magnitude (average axial rotation of 3.7° *versus* 6.0° for the wedges and Headbed, respectively; average lateral bending of 3.4° *versus* 4.9° for the wedges and Headbed, respectively). The wedges also appeared to provide better absolute fixation of the head when compared with the towel method; however, the differences were not statistically significant. Importantly, there were no statistically significant differences between the techniques in terms of the relative motion occurring across the neck (axial rotation, $P = 0.13$; lateral bending, $P = 0.31$).

There was a trend, in three of the four primary measures (relative lateral bending excepted), for range of movement to increase slightly after exposure to 6 minutes of platform motion (Figure 4C); however, this was statistically significant only when considering absolute lateral bending ($P = 0.015$). There was also a tendency for the range of motion to increase more with time when using the towels or the Headbed than when using wedges; however, this apparent interaction between technique and exposure time was not statistically significant. The same trends that were seen after 6 minutes of exposure were also evident after 12 minutes of exposure in the three volunteers who were tested for this longer duration.

Anecdotally, volunteers reported that the motion imposed by the moving platform effectively simulated the motion of a moving vehicle. In addition, volunteers reported no difficulty in remaining relaxed throughout the experimental sessions. This was confirmed by the ab-

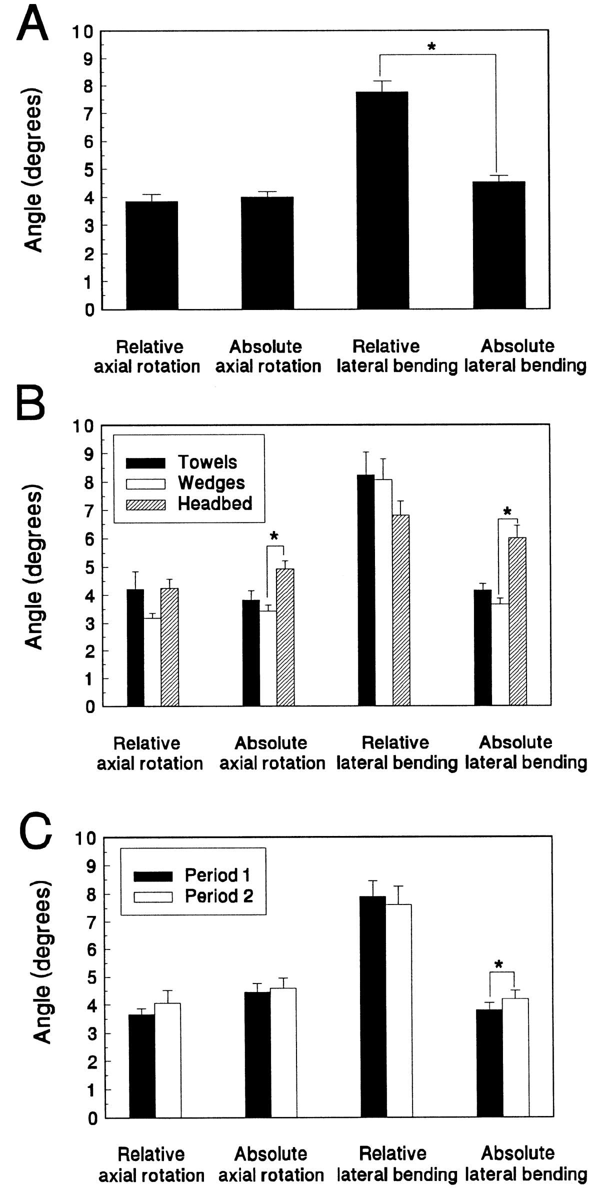

Figure 4. Average peak-to-peak range of head motion and the corresponding standard deviation for all four experimental measures of head motion ("absolute" measures characterize the motion of the head with respect to the fracture board, "relative" measures characterize the motion occurring across the neck, *i. e.,* head motion measured relative to the trunk). **A,** Overall means from all study participants, all immobilization techniques, and both measurement periods (periods 1 and 2, as defined below). **B,** Means for each of the three techniques. **C,** Means for each of the two 15-second measurement periods (period 1 = start of trial, period 2 = after 6 minutes of platform motion). *Significant difference ($P < 0.05$).

sence of any measurable electromyographic activity from the neck muscles.

Discussion

The results of the current study, which quantify head motion during simulated vehicle motion, are highlighted by three main observations. First, substantial amounts of head and neck motion were recorded during the simulated vehicle motion, regardless of the method of immobilization. The levels of neck motion were, in fact, judged by a panel of three experienced neurologists and neurosurgeons to be "clinically significant" with regard to the potential contribution to spinal cord injury. Second, although the focus on reducing movement commonly is directed at immobilizing the head, the results of this study indicate that the movement of the trunk can have an equally important influence on motion occurring across the neck. This was reflected by the differences between absolute and relative lateral bending. Third, small improvements in efficacy, resulting from the immobilization technique used, appeared to be restricted to reduction in the absolute range of motion and to a slight reduction in the progressive increase in motion occurring over the duration of the test. Given the influence of the trunk motion noted above, these small improvements in fixation of the head to the fracture board did not translate into a reduction in relative motion across the neck. Thus, although the results of this study support the hypothesis that the new wedge method would provide somewhat improved head fixation, this benefit did not lead to improved immobilization of the neck when using the current method of trunk fixation.

The average amount of relative lateral bending motion measured in the current study was approximately 8°. This amplitude of motion is comparable with the 7° of fracture-site sagittal plane angulation occurring during position changes in patients treated by halo-vest.[1] It is significant that studies reporting lateral bending during maximal voluntary contractions yield values that are often not much different from those in the current study. For example Graziano et al[6] reported lateral bending ranging from 8 to 16°, averaged across different immobilization methods. Other investigators, such as Podolsky et al,[11] reported lateral bending of nearly 4° in response to maximal efforts when immobilizing with sandbags and tape. The similarities between magnitude values found in previous studies and the results of the current study are remarkable, because in those static trials, volunteers were attempting to execute maximal contractions to bend the neck against the immobilization device. In contrast, in the current study, the volunteers were passive, secured to the fracture board, and subjected to simulated vehicle motion. The resulting size of the passively induced head movement reaffirms the concern that more effort should be directed at understanding the efficacy of immobilization techniques during dynamic movement conditions.

The current study highlights the significance of trunk motion as a factor influencing the efficacy of immobilization strategies. It is likely that motion of the trunk relative to the fracture board contributed to the larger values of lateral bending measured across the neck, *versus* the absolute measures of lateral head motion. Consequently, limiting the degree of lateral trunk motion would appear to be a significant issue when considering techniques for minimizing cervical spine movement. This confirms concerns raised by Mazolewski and Manix,[10] who explored variations in strapping techniques to improve the control of lateral body motion. The method of strapping the trunk varies among countries and regions; therefore, the results of the current study are most directly applicable to centers using strapping techniques that are similar to the technique used in this study. More generally, however, the current results suggest that improvements in fixation of the head without comparable fixation of the trunk may be ineffective in reducing spinal motion at the neck. It seems likely that the improved head fixation provided by the new wedge system could be effective in limiting relative motion across the neck if combined with an effective system of trunk fixation. Placement of wedges under the thorax, in combination with transverse strapping, is one possibility; however, further research is needed to determine the optimal combination of trunk and head fixation methods. Such research also should examine whether other commercially available head immobilization systems, not tested in the current study, provide any additional benefit.

The current study is limited by the inability to make direct inferences about the motion of the spinal cord. There is some evidence, however, that such kinematic techniques can provide an acceptable tool to estimate overall movement of the cervical spine.[5] Although the current authors were careful to adhere markers to landmarks that represent the integrity of the skeletal system, they were unable to provide a direct measure of the relative changes in the spinal column. Furthermore, the association between spinal column movement and the potential for spinal cord injury remains unclear.[6] It is conventional wisdom that, given this uncertainty, one would attempt to achieve complete immobilization. To this end, kinematic assessment of the degree of immobility has value. One would expect the degree of relative motion occurring across the neck, rather than the absolute motion of the head itself, to have the greater relevance in terms of reducing the potential for damage to the spinal cord.

Another potential limitation of the current study is that the protocol was restricted to motion delivered in the lateral direction. This motion, as the authors had intended, is most likely to expose limitations of immobilization devices in their ability to control lateral bending (adduction/abduction). Anecdotally, experienced ambulance riders have expressed concern about the potential for motion to occur in this direction, *e.g.*, when turning corners or switching lanes. It is possible, if one were to simulate vehicular motion in other directions, that limitations of immobilization devices also would be revealed for controlling axial rotation and/or flexion–extension. The current authors' pilot tests did indicate, however, that little or no head motion occurred when moving the patient in the forward–backward direction. Finally, it should be reiterated that the current study was limited to higher-frequency accelerations, which were intended to simulate the sudden jarring movements that would be likely to cause loosening of the fixation. However, it is possible that the large low-frequency accelerations that occur when driving around curves in the road could place additional demands on the immobilization system. This possibility should be examined in future studies.

Limitations notwithstanding, the current study clearly indicates the importance of considering the influence of dynamic whole-body movement on the efficacy of immobilization techniques. Moreover, the results demonstrate that techniques intended to immobilize the cervical spine during transport must address the control of both head and trunk motion. After comparing the different fixation methods, the authors conclude that it may be possible to achieve some small improvements in fixation of the head to the fracture board by placing wedges under the head; however, the benefits of any fixation method, in terms of cervical spine immobilization, are likely to be limited unless the motion of the trunk is also controlled effectively.

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Point of View

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This is an interesting report that brings to mind a couple of studies on the possible neuro-regulatory function of the facet capsules controlling muscular balance in the lumbar spine. Cavanaugh et al[1] detected electrical discharges in the dorsal nerve root by mechanically stimulating the lumbar facet capsule on the contralateral side. Indahl et al[2] induced reactions in the multifidus on the same side and level by mechanically stimulating the lumbar facet capsule. If this mechanism is the same for the cervical spine, one would expect the extensors to go into spasm in the case of cervical fracture dislocation. This may be why no problems are encountered during transport, even though some neurosurgeons are of the opinion that neck motions are substantial. There is anecdotal evidence that spasms are observed during surgery, which may require the cutting of the extensors to restore alignment. The care exercised by emergency medical services technicians in the transport of patients with neck injuries is admirable. However, in some cases, extreme care may not be necessary and, in fact, may be to the detriment of the patient if there are other life-threatening injuries that require immediate attention in the emergency room.

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