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CERVICAL SPINE MOTION DURING EXTRICATION

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☐ **Abstract—Background: It has been estimated that up to one-quarter of spinal cord injuries may be significantly worsened during extrication or early treatment after a motor vehicle accident. Study Objectives: The purpose of this study was to analyze the planar motions of the head relative to the torso during extrication from an automobile in a laboratory setting. Methods: Video motion capture was used to quantify the range of motion of the head relative to the torso in 10 participants as they were extricated from a mock motor vehicle during four different extrication techniques: 1) Unassisted Unprotected, 2) Unassisted Protected with a cervical collar (CC), 3) Assisted and Protected with a CC, and 4) Assisted and Protected with a CC and Kendrick Extrication Device. Results: The results indicated a significant decrease in movement for all motions when the driver exited the vehicle unassisted with CC protection, compared to exiting unassisted and without protection. Decreases in movement were also observed for an event (i.e., Pivot in seat) during extrication with paramedic assistance and protection. However, no movement reduction was observed in another event (i.e., Recline on board) with both paramedic assistance and protection. Conclusion: In this study, no decrease in neck movement occurred for certain extrication events that included protection and assistance by the paramedics. Future work should further investigate this finding. © 2013 Elsevier Inc.**

☐ **Keywords—immobilization; vehicle extrication; spine; transportation of patients; video motion capture**

INTRODUCTION

Most injuries to the cervical spine are due to motor vehicle accidents (1). It has been estimated that up to one-quarter of spinal cord injuries may be significantly worsened during transport or early treatment (2–4). Hence, the American College of Surgeons recommends full spinal immobilization during extrication after a motor vehicle accident (5). Little evidence exists regarding the cause of the additional injuries. Potential causes could include inflammation or other physiological factors, application of protective equipment, extrication from the vehicle, and transportation to the ambulance. Any injury associated with application, extrication, and transportation might be preventable.

The extrication process includes the application of a cervical collar (CC), the addition of lateral immobilizing devices such as the Kendrick Extrication Device (KED), and immobilization on a long backboard (3,6,7). Two main principles are followed during the extrication process to prevent motion of the spine and further injury: 1) maintain spinal alignment and 2) minimize body twisting. Normal spinal alignment has an “S” shape (8). This “S” shape can be disrupted, especially in the cervical region, during a motor vehicle accident, resulting in hyperextension, hyperflexion, lateral flexion, compression, distraction, or axial rotation.

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Previous efforts to investigate spinal motion have involved cadaver studies using three-dimensional photogrammetry and radiographic analysis of cervical motion (6,9–11). Roozmon and colleagues suggested that a more comprehensive motion capture system is the best method for further study of motion in the cervical spine (12,13). Video motion capture systems have been used to study the specific motions of many parts of the body, for example, gait and spinal motion and upper extremity movement (14,15).

Our previous initial pilot investigation is, to our knowledge, the only recent work that has attempted to quantify motion of the cervical spine during the extrication process (16). Using video motion-capture methods, we found that the motion of the cervical spine was greater when participants were extricated onto a spine board compared to getting out of the vehicle independently, wearing a cervical collar. Our previous investigation was primarily limited by a small cohort of participants (n = 3), and separating the composite movement angles into their component principal motion planes (i.e., sagittal, frontal, transverse planes). The purpose of this follow-up pilot study was to analyze the planar motions of the head relative to the torso during extrication from a mock automobile in a laboratory setting. The general hypothesis was that there would be a significant decrease in movement of the head relative to the torso for the extrication techniques compared to exiting the vehicle unassisted and unprotected.

Figure 1. Application of the cervical collar by Emergency Medical Services personnel in the mock automobile. Visual monitoring cameras recording head and trunk movement of victim.

MATERIALS AND METHODS

To understand the physical boundaries imposed by a motor vehicle, a 2001 Toyota Corolla that had been involved in a high-speed head-on collision, and had significant damage to the interior compartment, was reconstructed in the laboratory (Figure 1). The frame of the vehicle was constructed from ½-inch PVC (polyvinyl chloride) pipe and bent wire. Features included ground height, floorboard space, dash, center console, steering wheel, ceiling, and doors. All deformities rendered by the accident were included in the model. The actual seats from the vehicle were removed and placed in the mock vehicle. To permit camera identification of the video motion-capture surface markers, the seat backs were replaced with Plexiglas.

Sixteen participants were recruited by word of mouth for the investigation (six women, four men; age 28 ± 7 years; height 155 ± 12 cm; weight 78 ± 16 kg). Ten of the participants were Emergency Medical Services (EMS) personnel (paramedics) with >5 years of experience in the field. The EMS participants took turns extricating the "accident victim driver" participants from the vehicle. They worked in pairs. Four of the EMS personnel also served as accident victims (i.e., drivers) and were extricated from the vehicle. The remaining six participants were students who knew little about the process of extrication. They portrayed drivers and were extricated from the vehicle by the EMS pairs. Ten participants were an adequate number to generate data for a power analysis for a future investigation. The study was approved by the Institutional Review Board. Written informed consent was obtained from all participants.

Before data collection, the driver had 6-mm reflective surface markers placed on the head (forehead, crown, zygomas), at C7, and the trunk (acromion, humerus, clavicle, sternum, anterior superior iliac spine, and greater trochanters bilaterally). In collecting the data (three trials for every technique), each driver started from a sitting position in the driver's seat of the mock automobile and was extricated by two EMS personnel using each of four randomly ordered techniques:

1. Unassisted Unprotected: The "driver," without neck protection (i.e., unprotected), was allowed to exit the vehicle on his or her own volition (i.e., unassisted), walk over to the long backboard, and lie down on it. The only instruction given to the participant was to exit the vehicle.
2. CC Unassisted Protected: Two EMS personnel applied the cervical collar (CC) to the driver. The driver, with a CC in place (i.e., protected), was allowed to exit the vehicle on his or her own volition, walk over to the long backboard, and lie down on it.
3. CC Assisted Protected: Two EMS personnel applied the CC to the driver. The driver, with the CC in place, was extricated head first via standard

technique by paramedics onto a backboard (9,17). Standard technique involved one paramedic, outside the car, inserting the backboard under the driver (between the driver and the seat). The second paramedic, inside the car on the passenger's seat, stabilized the CC and the driver's head while the left hip was elevated to accommodate the long board. The paramedics turned the driver such that he or she lined up with the backboard with the legs lying across the transmission console and in the passenger's seat. Then the paramedics laid the driver down onto the backboard, while controlling the head and neck to pass under the door frame. With the driver's head, shoulders, and hips flat on the backboard, the two paramedics slid the driver along the board until the legs were also flat on the board. The EMS personnel then secured the driver onto the board and the driver was transported to the ambulance.

4. CC KED Assisted Protected: Two EMS personnel applied the CC and KED to the driver. The driver, with CC and KED in place, was extricated head first via standard technique by two paramedics onto a long backboard (9,17).

Three trials for each extrication technique were carried out with each driver.

Surface marker video data of a single trial of each extrication technique for each participant were tracked (digitized) and edited to produce three-dimensional coordinates using standard Motion Analysis Corporation (Santa Rose, CA) software (accuracy ± 3 mm, resolution ± 2 mm) (18). A head segment was created by the crown and right and left zygoma markers. A trunk segment was created by the sternum and right and left acromion markers. The entire extrication movement was segmented into a series of experimental events (Column 1 of Table 1). Not all events took place for each technique. For example, the Unassisted Unprotected technique did not have CC or KED application events. The CC Assisted Protected technique did not have stand and walk-to-the-board events. The movement for each experimental event was then separated into its three principal planes of motion (i.e., flexion-extension in the sagittal plane, lateral flexion in the frontal plane, and rotation in the transverse plane). The maximum range of motion in each plane for each event was quantified (i.e., primary outcome measure). Repeated-measures analysis of variance was used to determine if significant differences existed for the experimental events as a function of the different techniques (with $p < 0.10$ as significant). A Tukey post hoc test was used to identify the significantly different techniques if a difference was detected. It should be noted that because this project was exploratory in nature (i.e., more about hypothesis generating than hypothesis

Table 1. Planar Range of Motion (i.e., Flexion-Extension in the Sagittal Plane, Lateral Flexion in the Frontal Plane, and Rotation in the Transverse Plane) Means and SDs (+) of Essential Extrication Events for the Four Extrication Techniques

	Unassisted			CC Unassisted			CC Assisted			CC KED Assisted		
	Unprotected			Protected			Protected			Protected		
Extrication Event	Flex-Ext (deg)	Lateral Flex (deg)	Rotation (deg)	Flex-Ext (deg)	Lateral Flex (deg)	Rotation (deg)	Flex-Ext (deg)	Lateral Flex (deg)	Rotation (deg)	Flex-Ext (deg)	Lateral Flex (deg)	Rotation (deg)
CC application	-	-	-	11.2 ± 7.0	11.2 ± 4.0	11.6 ± 5.5	11.2 ± 4.7	10.9 ± 6.4	7.5 ± 3.2	8.9 ± 4.0	6.0 ± 2.5	6.4 ± 2.1
KED application	-	-	-	-	-	-	-	-	-	24.0 ± 16.2	15.9 ± 18.2	12.6 ± 2.3
Pivot in seat	24.3 ± 6.8*	23.9 ± 8.7*	26.6 ± 12.8*	11.5 ± 3.9	4.8 ± 1.5	7.6 ± 6.0	16.2 ± 9.3†	10.3 ± 4.2*†	9.4 ± 5.0†	14.2 ± 9.3	10.6 ± 8.9*†	11.8 ± 10.8†
Recline on board	40.2 ± 15.3*	21.6 ± 10.3*	32.2 ± 15.1*	23.7 ± 10.6	12.3 ± 7.0	17.0 ± 11.4	28.7 ± 12.5	24.4 ± 11.7‡	22.9 ± 9.7	36.5 ± 22.7	31.3 ± 17.4*	27.7 ± 14.6*
Stand	31.7 ± 12.6*	19.5 ± 7.9*	25.9 ± 10.9*	9.9 ± 7.2	4.0 ± 2.8	9.5 ± 9.0	-	-	-	-	-	-
Walk to board	33.6 ± 17.5*	19.2 ± 5.7*	34.4 ± 19.7*	10.6 ± 7.7	5.1 ± 2.4	6.3 ± 3.6	-	-	-	-	-	-

CC = cervical collar; KED = Kendrick Extrication Device.
* Significantly different from CC Unassisted Protected ($p < 0.10$).
† Significantly different from Unassisted Unprotected ($p < 0.10$).
‡ Significantly different from CC KED Assisted Protected ($p < 0.10$).

testing), a less conservative level of significance was selected ($p < 0.10$ instead of $p < 0.05$).

RESULTS

The range-of-motion results indicated that the CC Unassisted Protected technique, for all experimental events across all three planes, had significantly less range of motion than the Unassisted Unprotected technique (Table 1). In fact, with the addition of the CC level of protection, range of motion was decreased by about 20° in many instances.

The results for the two Assisted Protected techniques (i.e., CC and CC KED), when compared to the Unassisted Unprotected technique, were not as straightforward. Similar to the CC Unassisted Protected technique, the two Assisted Protected techniques had significantly less range of motion than the Unassisted Unprotected technique in some instances. For example, five of the six range-of-motion values for the Pivot-in-seat extrication event, for the two Assisted Protected techniques, were significantly lower than the Unassisted Unprotected technique.

On the other hand, the two Assisted Protected techniques did not consistently offer the same level of protection as the CC Unassisted Protected technique. For example, the CC Assisted Protected technique had significantly greater range of motion than the CC Unassisted Protected technique for lateral flexion in the Pivot-in-seat event (10.3° ± 4.2 compared to 4.8° ± 1.5, respectively). Furthermore, two key results existed for the Recline-on-board experimental event for the CC and CC KED conditions (Figure 2). The first was that none of the results were significantly less than the CC Unassisted Unprotected technique. The second was that there was significantly greater range of motion for the CC KED Assisted Protected technique compared to the CC Unassisted Protected technique for both Lateral Flexion ($p = 0.010$, Figure 2B) and Rotation ($p = 0.048$, Figure 2C).

DISCUSSION

There is a paucity of literature quantifying neck movement in live participants during the extrication process (16,19). Our previous work used experimental conditions to evaluate neck motion (16). The results of the present investigation agreed with our previous work demonstrating reduced motion for the CC Unassisted Protected technique relative to the Unassisted Unprotected technique. The present work separates the motion into its principal planar components and reports on a larger cohort of participants (n = 10 compared to n = 3, respectively). The present work further supports the effectiveness of the CC and KED techniques in reducing motion during the Pivot-in-seat event. The general hypothesis indicating effectiveness in the techniques for reducing motion was supported here.

Previous work also indicated greater motion with CC and KED Assisted Protected techniques compared to the CC Unassisted Protected techniques. The current investigation further delineates these results, recognizing that there was not a significant decrease in motion for the CC and KED Assisted Protected techniques compared to the Unassisted Unprotected technique for the Recline-on-board event. In fact, there was a significantly greater range of motion in the CC KED Assisted Protected technique compared to the CC Unassisted Protected technique. The general hypothesis indicating effectiveness in the techniques for reducing motion was not supported here.

Whereas full spinal immobilization is recommended by the American College of Surgeons during extrication after a motor vehicle accident, it has been estimated that up to one-quarter of spinal cord injuries may be significantly worsened during extrication (3–5). The results of the present investigation point to two key concepts. The first is that it seems to identify potential events during the Assisted Protected extrication techniques (both CC and CC KED) when additional injury may likely occur

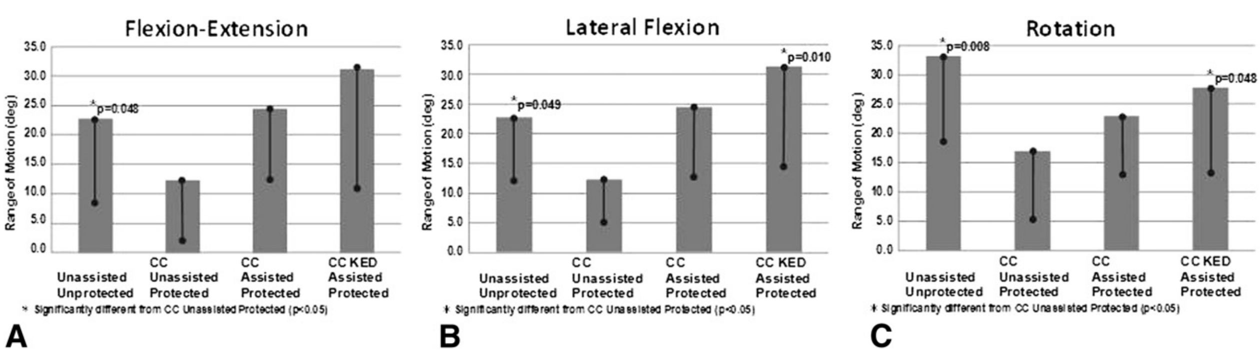

Figure 2. Flexion-extension (A), lateral flexion (B), and rotation (C) range of motion means and SDs of the Recline-on-board experimental event for the four extrication techniques. None of the range of motion values for the cervical collar (CC) Assisted Protected and the CC Kendrick Extrication Device (KED) Assisted Protected techniques was significantly different from the Unassisted Unprotected technique. The range of motion in Lateral Flexion and Rotation for the CC KED Assisted Protected technique was significantly greater than the CC Unassisted Protected technique.

(e.g., Reclining on board). The second is the need to discover the factors responsible for the lack of reduction in movement. The two prominent factors are equipment and paramedic actions. Because movement is significantly reduced from the Unassisted Unprotected technique to the CC Unassisted Protected technique when equipment is added (e.g., CC) but no paramedic actions are involved, it may be important to focus on actions of the paramedics. It is possible that a lack of coordination and timing between the paramedic actions could serve to increase head motion relative to the torso.

Limitations

Three limitations to this study are noteworthy. The first is that four of the 10 drivers who were extricated from the vehicle were paramedics. Their knowledge of basic extrication methods may have biased the results in some way. It should be noted that when we compared the results for the paramedic group with the non-paramedic group (independent *t*-test), there were no obvious trends separating one group from another and there were no significant differences in any of the variables. The second limitation is that surface marker occlusion due to the automobile model and movements of the driver and paramedics made some of the tracking difficult. In general, surface marker occlusion occurred in 1–15% of the data collected for the participants. The average was 3% of the data missing; one person had 10% and another had 15% missing. Sophisticated editing methods permitted reconstruction of the data, yet it would have been better if the markers were more visible for the cameras during the data collection sessions. Future work could include more cameras to increase marker visibility. The third limitation is that only the planar range of motion as a whole was quantified. The range of motion was not separated into its individual components. For example, in the sagittal plane, individual values for flexion and extension might have provided additional insight regarding the potential for additional injury.

CONCLUSION

The present investigation analyzed the planar motions of the head relative to the torso during extrication of a driver from a mock automobile after an accident. The general hypothesis that movements would be reduced using neck protection was supported. There was a significant decrease in movement for all motions when the driver exited the vehicle unassisted with protection. Decreases in movement were also observed for an event (i.e., Pivot in seat) during extrication with paramedic assistance and protection. However, no movement reduction was observed in another event (i.e., Recline on board) with both paramedic assistance and protection. Future work should investigate why no decrease in neck movement occurs for certain events that include protection and assistance by the paramedics.

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ARTICLE SUMMARY

1. Why is this topic important?

Up to 25% of spinal cord injuries may be worsened during extrication after a motor vehicle accident.

2. What does this study attempt to show?

The study attempts to demonstate that the increased injury speculation could indeed be true.

3. What are the key findings?

There was a decrease in movement for all motions when the driver exited the vehicle unassisted with cervical collar protection, compared to exiting unassisted and without protection. However, no movement reduction was observed in an event (i.e., Recline on board) with both paramedic assistance and protection.

4. How is patient care impacted?

Whenever possible, the driver should have the cervical collar applied and be allowed to exit the vehicle without assistance.