Motion Within the Unstable Cervical Spine During Patient Maneuvering: The Neck Pivot-Shift Phenomenon

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Background: Cervical extrication collars are applied to millions of blunt trauma victims despite the lack of any evidence that a collar can protect against secondary injuries to the cervical spine. Cadaver studies support that in the presence of a dissociative injury, substantial motion can occur within the occipitocervical spine with collar application or during patient transfers. Little is known about the biomechanics of cervical stabilization; hence, it is difficult to develop and test improved immobilization strategies.

Materials: Severe unstable injuries were created in seven fresh whole human cadavers. Rigid collars were applied with the body in a neutral position. Computed tomographic examinations were obtained before and after tilting the body or backboard as would be done during patient transport or to inspect the back. Relative displacements between vertebrae at the site of the injury were measured from the Computed tomographic examinations. The overall relative alignment between body and collar was assessed to understand the mechanisms that may facilitate motion at the injury site.

Results: Intervertebral motion averaged 7.7 mm ± 6.8 mm in the axial plain and 2.9 mm ± 2.5 mm in the cranial-caudal direction. The rigid collars appeared to create pivot points where the collar contacts the head in the region under the ear and where the collar contacts the shoulders.

Discussion: Rigid cervical collars appear to create pivot points that shift the center of rotation lateral to the spine and contribute to the intervertebral motions that were measured. Immobilization strategies that avoid these neck pivot-shift phenomena may help to reduce secondary injuries to the cervical spine. The whole cadaver model with simulation of patient maneuvers may provide an effective test method for cervical immobilization.

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Cervical extrication collars are applied to millions of blunt trauma victims, with the intent of protecting the occipitocervical spine in the rare event of a severe injury.[1] There is evidence that collars can restrict motion of the head when applied to healthy, uninjured volunteers.[2] However, there is no evidence that collars can effectively protect against secondary injuries to the vital structures of the neck in the presence of a severe dissociative injury.[2] Preliminary evidence suggests that collars do not protect the unstable spine during patient transfers.[3–5] A recent whole human cadaver study documented the separation that can occur between cervical vertebrae when an extrication collar is applied in the presence of a severe dissociative injury.[6]

The prior whole cadaver study only considered one aspect of spine immobilization protocol, the initial effect of collar application to a prone body aligned on a back board.[6] However, during patient transport, transfers, and tilting the patient to examine the back, a wide range of motions can occur. Collars are specifically intended to protect the spine during motions associated with these patient maneuvers. The purpose of this study was to provide additional data to better understand the biomechanics of cervical immobilization with collars during patient maneuvers and to identify strategies that may help to achieve more effective immobilization technology.

MATERIALS AND METHODS

Seven fresh whole human cadavers were obtained through the anatomic gifts program at the Department of Anatomy, Baylor College of Medicine. They were kept in a refrigerated state (2°C) before use and examined at room temperature after cessation of rigor mortis, when their neck motion was indistinguishable from that of asymptomatic live volunteers.[7–9] None of the cadavers had any prior cervical conditions, interventions, or anomalies that could potentially interfere with intervertebral motion.

The anterior and posterior restraints to intervertebral motion between the first and second cervical vertebrae were surgically destroyed through a midline posterior incision. The muscles were first carefully dissected longitudinally away from the posterior elements and their fascial and ligamentous attachments, but were otherwise left intact. A dissociative injury was simulated by severing the nuchal ligament, the left and right facet joint capsules, the tectorial membrane, the inferior aspect of the cruciate ligament, and the anterior longitudinal ligament. In addition, the odontoid was severed at its base from the body of C2. The damage created to the ligaments, facet joints, and odontoid was intended to replicate injury patterns observed in our trauma patients and in previously reported dissociative injuries.[10–12] The presence of a severely unstable injury, and initial reduction of any surgically created mal-alignment, was verified by fluoroscopic imaging. In all cadavers, a conventional extrication collar

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(Ambu Perfit Ace, Ballerup, Denmark) was applied using routine emergency medical service protocol. Collars were applied to represent the variations seen in the emergency room: some were properly sized, some were oversized, and some were undersized. Furthermore, initial reduction of any surgically created malalignment was verified by fluoroscopic imaging. In all cadavers, application of a rigid collar required lifting of the head while maintaining in-line stabilization to apply the posterior section of the collar. Therefore, the head was once again reduced after collar application just before the initial computed tomographic (CT) examination.

All cadavers were scanned using contiguous, 0.67-mm thick axial CT sections, spaced 0.33 mm apart, with a 140 mm field of view (Brilliance 64, Philips Medical Imaging, Amsterdam). With the collar applied, a baseline scan was obtained with the cadaver in a neutral prone position, and a second scan was obtained with the body rolled sufficiently to one side to examine the back, as is done in routine clinical practice (two cadavers), or the body was tilted 10 degrees to 20 degrees simulating tilting of a patient to examine the back or tilting of the patient during transfers (five cadavers). On two cadavers, an additional CT examination was obtained with the body rolled to examine the back but with no collar applied. Rolling of the body was performed with three to four people attempting to perform the roll while minimizing any relative motion between the head and the body.

CT scan series before and during the tilt were scaled and registered so that C2 was in the same spatial location in both scans (ImageJ; National Institutes of Health, Bethesda, MD, and the Align3TP plugin to ImageJ). Registering C2 in the scans facilitated more accurate assessment and measurement of relative motion. The aligned scans were transferred to Osirix for analysis and measurements using the image fusion and measurement tools.[13]

Relative displacement between C1 and C2 was measured in the axial plane at the level of the middle of C2 and in the mid-sagittal or coronal planes, depending on where the greatest cranial-caudal intervertebral motion was observed. These measurements represented the clinical effect of spinal cord compression/shear and spinal cord traction, respectively.

RESULTS

The baseline CT scans supported that abnormal separation can exist between cervical vertebrae at the sight of an injury while a collar is in place. The average distraction for right and left facets was 9.23 mm (range, 0.36–17.5 mm; SD, 6.21) and 5.24 mm (range, 1.85–9.2 mm; SD, 2.66). Tilting of the cadaver or tilting the back board that the cadaver was on caused significant intervertebral motion in every cadaver (see Video, Supplemental Digital Content 1, http://links.lww.com/TA/A45). Measurements of two clinically relevant plains are displayed in Table 1 and Figure 1. The average motion in the axial plain was 7.74 mm (range, 3.31–22.8 mm; SD, 6.8). The average motion in the cranial-caudal direction was 2.93 mm (range, 0–7.79 mm; SD, 2.51). Similar motion was observed in the cadavers that were tilted without a collar applied, but with data for only two bodies, it cannot be determined whether the collars provided any benefit. The cadavers were carefully examined while tilted to identify how the collars interact with the body.

TABLE 1. Measurements of Relative Motion Between C1 and C2 in Two Plains From CT Scans Acquired Before and During the Tilt Maneuvers

Cadaver Number	Horizontal Motion (mm)	Longitudinal Motion (mm)
1	6.23	4.33
2	3.31	2.11
3	22.8	1.48
4	3.37	0
5	7.32	1.96
6	5.14	2.85
7	6.06	7.79
Average	7.74	2.93

DISCUSSION

In this study, tilting of the cadavers created significant relative motion at the injury site in every case, despite the use of standard rigid cervical collars, which are intended to stabilize an unstable spine. It is likely that within the wide spectrum of injuries that occur in actual trauma patients, similar intervertebral motions can occur during extrication, transport, transfers, and management of trauma patients. This study adds to the existing evidence for significant motion between vertebrae at the site of a severe injury during patient transfers or procedures with a collar applied.[3–5,14,15] This study also provides evidence to support a test method that could be used to test new cervical immobilization strategies.

The mechanisms that result in intervertebral motion when a patient is tilted while wearing a collar are poorly understood. Based on examining the interaction of collars with the body, one hypothesis is that a collar acts as a relatively stiff strut between where it contacts the base of the head and where it contacts the shoulders. These are points where pressure sores can develop when a collar is left on a patient for an extended period.[16] These points of contact regions act in part as pivots about which the head can rotate during patient maneuvers. The relatively large distance between these pivot points and the spine can help to explain the large motions that were measured between vertebrae at the site of the injury. Although the axis of motion is controlled by the cervical spine in an uninjured person, the axis of motion is transferred laterally toward the rigid plastic collar walls in an unstable injured neck. This motion may metaphorically be likened to the better known knee pivot shift seen after anterior cruciate ligament injury.[17]

The clinical significance of these observations cannot be documented by a cadaver study. However, the possibility of motion caused by a pivot shift with an unstable neck injury may result in the stretching and translation of soft-tissues,

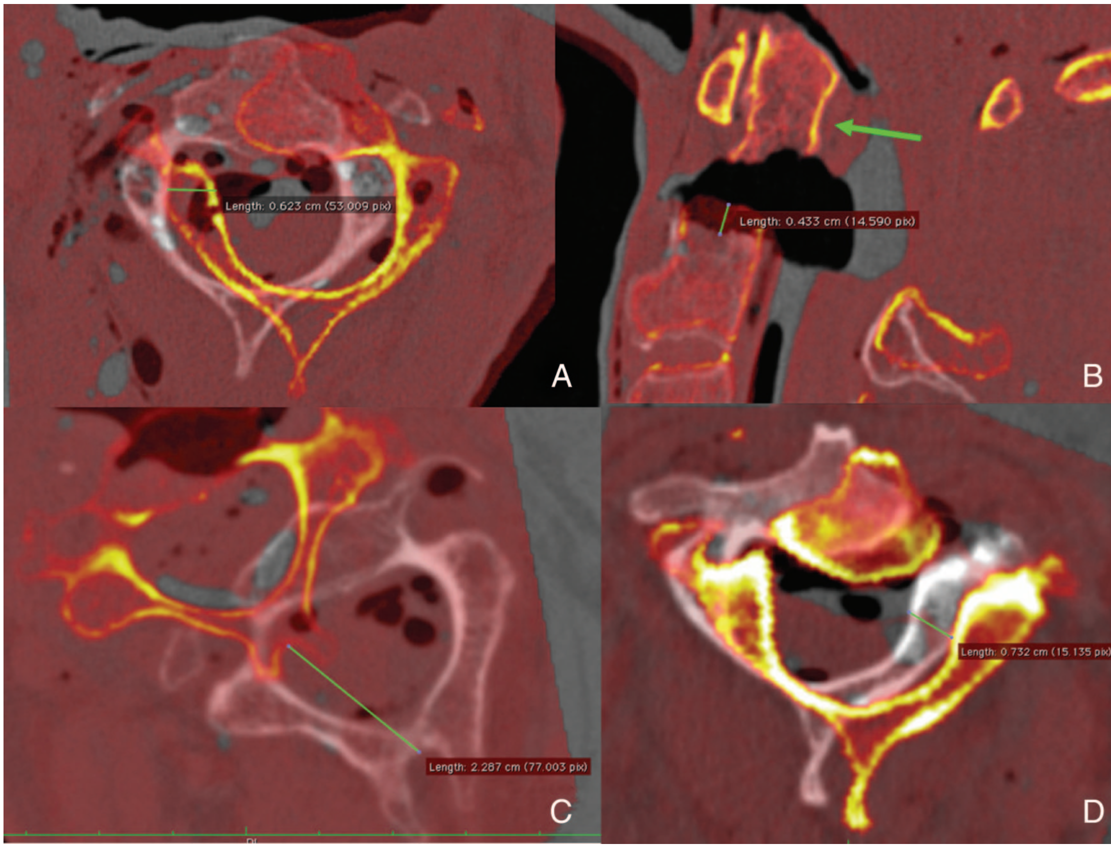

Figure 1. Sections from three-dimensional reconstructions of CT data showing axial plane and cranial-caudal motion during the tilt in cadaver 1 (*A* and *B*, respectively), and axial plane motion in cadavers 3 and 5 (*C* and *D*, respectively) while collar was applied. To create these images, CT examinations taken before and after the patient maneuver were spatially aligned so that C1 was in the same position in both scans. The *gray areas* in the images show the relationships within the occipitocervical spine before the patient maneuver, and *yellow-orange regions* show the relationships after the patient maneuver. The *green arrow* points to the C1 vertebra that is in the same position in both pre- and post-maneuver CT examinations.

including the spinal cord, spinal canal, and vertebral arteries, potentially leading to spinal cord ischemia and secondary injury. The magnitude, direction, and duration of motion that will result in neurologic deficit have not been adequately studied, but it is unlikely that the motion is of benefit to the trauma victim.

It is well known that trauma patients can experience major neurologic deterioration during the interval between the time of injury and definitive hospital treatment as a result of a lack of adequate cervical spine immobilization.[18–20] This is particularly true for patients with occipitocervical dissociative injuries, because the resulting vulnerability of vital neurologic and vascular structures, including the brain stem, can lead to devastating consequences including quadriplegia, respiratory device dependency, and frank death.[21–26]

The study has several limitations. Aside from the small number of cadavers studied, and the small subset of patient maneuvers that were studied, the protective muscle tone present in conscious patients cannot be reproduced in this model. However, previous studies demonstrate that intact intervertebral motion in this kind of whole cadaver model is indistinguishable from asymptomatic volunteers.[7–9] The whole cadaver model may represent the worst-case clinical scenario of an unconscious, obtunded, or sedated patient where active muscle stabilization of the spine is eliminated. The possibility of a complex interaction between collar design, collar size, neck size, injury severity, and other variables may exist but was not addressed in this study.

The Advanced Trauma Life Support protocol mandates assessing the airway, breathing, and circulation with proper in-line stabilization of the neck and complete survey of the patient including the back while carefully rolling the patient for inspection and palpation.[1] It is a stated goal of the Advanced Trauma Life Support protocol to stabilize the cervical spine during patient management. A variety of collars, backboards, and other equipment and techniques are being used in an attempt to achieve spine stabilization, largely without any validation of efficacy when used in the presence of a severe cervical injury. Randomized, prospective clinical trial designs are challenging in this domain. Nevertheless, basic cadaver studies can provide valuable insight into potential clinical efficacy.

CONCLUSIONS

This study supports several previous studies in suggesting that, while maneuvering a trauma patient, grossly abnormal displacements between the occiput and the spine can occur in the presence of a dissociative injury to the occipital-cervical region, even when a collar is applied to protect against such displacements. The results suggest that the point of contact between a rigid collar and the body may contribute to intervertebral motions at the site of an injury, and this may be one area to address in the development of improved immobilization strategies. Optimization of cervical stabilization methods, with validation that includes high-quality scientific evidence of efficacy, may reduce the number of preventable deaths and spinal cord injuries that occur after blunt trauma. Although the sample size of this study was too small to reach definitive conclusions, the data support the need for additional research to optimize stabilization of the head/neck/shoulder complex during trauma patient maneuvers.

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EDITORIAL COMMENT

The accepted inadequacy of external orthoses for the unstable cervical spine has made internal fixation as the definitive state-of-the-art for management of such diagnoses. With this fact in mind, the Baylor findings in a small cadaver study are not surprising.[1]

Their focus actually is on a particular inadequacy of collars envisioned as a pivoting phenomenon where two principal posterior collar contact points lever and displace the disjointed spinal elements. Whether this thesis is important or not can be debated. It could be a flaw in emergency collar inventory, fitting, or design. Who knows. Or, in light of the accepted inadequacy of external orthotics, who cares. Arguably, the more compelling question is whether there is a place for collars in emergent protection of the injured cervical spine or are they simply a gimcrack?

The incidence of second injuries to the spinal cord in the extraction of accident victims under the best of EMT performance is not known and would be difficult to determine. However, in an effort to minimize that incidence, paramedical gospel is the application of a cervical collar, maintaining the neck in in-line and in a neutral position. By definition, this gospel implies the deliberate movement of the neck to apply an orthotic known to be nonprotective. Furthermore, the neutral and in-line admonition implies that the patient's neck position can be safely adjusted to "look better" without a shred of evidence that this might be a safer strategy than avoiding any unnecessary neck movement whatsoever. (Recall the gallows joke of the crashed motorcycle rider having the habit of wearing his jacket backwards described as "fine until we turned his head around.")

In a conclusion common to many small study reports, the authors recommend that more work should be done in this area. In my opinion that might be best in refinements of extraction methods with an eye to only that neck movement necessary to resuscitation, collar be damned.

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