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Biomechanical analysis of cervical orthoses in flexion and extension: A comparison of cervical collars and cervical thoracic orthoses

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Abstract—The analysis of current cervical collars (Aspen and Miami J collars) and cervical thoracic orthoses (CTOs) (Aspen 2-post and Aspen 4-post CTOs) in reducing cervical intervertebral and gross range of motion in flexion and extension was performed using 20 normal volunteer subjects. The gross sagittal motion of the head was measured relative to the horizon with the use of an optoelectronic motion measurement system. Simultaneous measurement of cervical intervertebral motion was performed with the use of a video fluoroscopy (VF) machine. Intervertebral motion was described as (1) the angular motion of each vertebra and (2) the translational motion of the vertebral centroid. We used surface electromyographic (EMG) signal data to compare subject efforts between the two collars and between the two CTOs. Each orthosis significantly reduced gross and intervertebral motion in flexion and extension ($p < 0.05$). No statistically significant differences were found between the Miami J and Aspen collars in reducing gross or intervertebral sagittal motion, except at C5-6. Both CTOs provided significantly more restriction of gross and intervertebral flexion and extension motion as compared to the two collars ($p < 0.05$). The Aspen 2-post CTO and 4-post CTO performed similarly in flexion, but the Aspen 4-post CTO provided significantly more restriction of extension motion ($p < 0.05$).

Key words: biomechanics, brace, cervical, cervical thoracic orthoses (CTO), collars, extension, flexion, orthosis, spine.

INTRODUCTION

Semirigid cervical collars and cervical thoracic orthoses (CTOs) are routinely used both nonoperatively to protect the cervical spine after injuries and postoperatively to immobilize the spine following surgical reconstruction [1–3]. It is important that the prescribing physician recognizes the differences between the function of cervical orthoses, so they may make informed decisions as to which orthosis is most appropriate for a specific condition. The capability of an orthosis to immobilize the spine is a primary measure of its effectiveness.

Abbreviations: CTO = cervical thoracic orthosis, EMG = electromyographic, IRB = Institutional Review Board, SOMI = Sternal Occipital Mandibular Immobilizer, USMC = U.S. Manufacturing Corporation, VF = video fluoroscopy.

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Testing the most recent designs of orthoses is essential to provide current information regarding their effectiveness in restricting motion.

Investigators have used various methods, including cineroentgenography, goniometry, and conventional radiography, in healthy volunteers to quantify the capability of various cervical orthoses to restrict the cervical spine motion during flexion, extension, axial rotation, and lateral bending [4–12]. Many of these studies have investigated the capability of orthoses to limit gross motion of the cervical spine [6,11,13]. While some studies have examined intervertebral motion limitation [5,8,9], comparative data on the more current cervical collars and CTOs have been lacking.

Few of the current cervical collars and CTOs have been compared for their effectiveness in reducing both gross and intervertebral motion. Sharpe et al. evaluated motion restriction of a contemporary CTO manufactured by the U.S. Manufacturing Corporation (USMC) using radiography [7]. Although Sharpe et al. reported that the orthosis was effective in controlling flexion below C1, the group did not test other devices for comparison. Other studies have looked at the mechanical restriction of traditional older versions of CTOs, such as the SOMI (Sternal Occipital Mandibular Immobilizer), 2-poster, and 4-poster [9]. These are older studies that did not test more contemporary designs.

The objectives of this study were (1) to compare the efficacy of two current cervical collars (Aspen and Miami J) and two current CTOs (Aspen 2-post and Aspen 4-post) (**Figure 1**) in reducing the *cervical* intervertebral and *gross* range of motion in flexion and extension in normal volunteer subjects, and (2) to demonstrate the application of a new method of measuring the intervertebral motion restriction capability of cervical orthoses.

To comply with the Institutional Review Board's (IRB's) maximum allowable radiation dosage, we could test only four orthoses. The Aspen collar, the Aspen 2-post, and the Aspen 4-post CTOs were selected to investigate the effect of adding rigid thoracic extensions anteriorly (Aspen 2-post), and thoracic extensions anteriorly as well as posteriorly (Aspen 4-post) to an Aspen collar. The Miami J was selected for testing because it represented the most commonly prescribed semirigid, extended-wear cervical collars in our practice. Also, the Aspen and Miami J are similar in appearance, construction, and clinical indication.

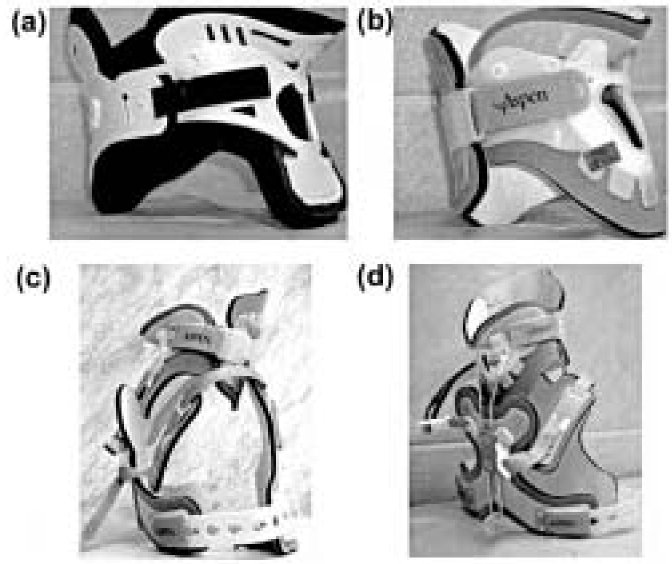

Figure 1.
Cervical orthoses tested: **(a)** Miami J collar, **(b)** Aspen collar, **(c)** Aspen 2-post CTO, and **(d)** Aspen 4-post CTO.

METHODS

Subjects

We recruited 20 normal volunteer subjects, 10 males and 10 females. None of the subjects reported a previous history of cervical injury or pathology. Subjects ranged in age from 21 to 44 years, with an average age of 31.5 years. The protocol for this study was approved by the IRB for Human Studies, and written informed consent was obtained from each subject. Each subject was informed of the protocol and risks for this study and was allowed to ask questions or exit the study at any time.

All instructions were communicated to subjects by the same certified orthotist. All cervical orthoses were applied by the same certified orthotist according to the manufacturer's written instructions.

Test Protocol

Surface EMG monopolar electrodes (Rochester Electro-Medical, Inc., Tampa, Florida) were placed on the appropriate neck muscles of the participants to record levels of muscle activity during each type of movement. Sterile alcohol prep pads were used to clean each electrode location. Four pairs of EMG electrodes were used, with two pairs placed on the anterior left and right sternocleidomastoid muscles and two pairs placed on the posterior cervical paraspinal musculature. To place these electrodes properly, we first asked each subject to place his or her hands on the forehead and push forward to emphasize the sternocleidomastoid muscles. Two electrodes were placed on the belly of each sternocleidomastoid muscle. Medical-grade tape was placed over the electrodes to prevent them from moving and/or sliding during neck movement. Next, the occipital protuberance was palpated. The subject was asked to place his or her hands on the back of the head and push backward to emphasize the posterior cervical musculature. Electrodes were placed on the paraspinal musculature approximately 4 cm below the occipital protuberance and approximately 2 cm to each side of the midline of the spine. One ground electrode was placed on the clavicle.

After EMG electrode placement, each subject was constrained at the chest and pelvis with the use of a harnessing device to minimize thoracic motion. A specially designed mouthpiece, with an attached target of infrared-emitting diodes, was placed in each subject's mouth to measure the gross cervical motion with an optoelectronic motion measurement system (Optotrak, Northern Digital Inc., Waterloo, Ontario, Canada) (**Figure 2**). The optoelectronic system provided three-dimensional (3D) motion of the head analysis in real time. The Optotrak position sensor consists of three individual cameras mounted in a single calibrated unit, placed anteriorly and above the subject. The subjects first practiced flexion and extension of their head and neck without an orthosis to confirm their understanding of instructions. Each subject was instructed to flex or extend his or her head and neck as far as possible using maximal effort and then return to their neutral position. We determined the neutral position by requesting each subject to stand in their normal upright posture. Each subject was tested without an orthosis and with each of the four different cervical orthoses. Each orthosis was checked for optimal fit before each trial. The order for these five trials for each subject was randomized.

Figure 2.
Video fluoroscopy set up in pilot study and taken during a flexion-extension trial. Each subject was constrained in a standing position with shoulder and pelvis straps. A specially designed mouthpiece was placed in each subject's mouth to track gross head motion, using an optoelectronic motion measurement system.

Video fluoroscopy (VF) images of cervical spine motion were captured into a computer at a rate of 4 frames/s. The average total VF exposure time for each subject for all flexion-extension trials was 62 s, with pulsing control settings at 2 mA and 70 kV. The average VF skin entrance exposure was 253 mrad per subject.* The maximum length of exposure time for any subject was 86 s (348 mrad), with an average total testing time of 1 hr, 8 min for each subject.

Data Analysis

The methodology subsequently described was used to analyze the VF flexion-extension data. The motion of each vertebra in the sagittal plane was described as (1) the angular motion of the vertebra (**Figure 3**) and (2) the translational motion of the vertebral centroid (**Figure 4**).

Intervertebral motion was calculated with the VF images captured into a computer. Five bony landmarks on each vertebra (C2 through C6) were digitized (one point at each of the four corners of the vertebral body and one point on the spinous process). For C1, five consistent bony landmarks (three inferiorly, two superiorly) were used. For C0, four points on the mouthpiece targets and one point on the mandible were used. For C7, only two points on the superior endplate were digitized, since viewing the inferior endplate of C7 in all subjects was not possible. Four line segments were defined for each vertebra (C1 to C6) by lines joining the point on the spinous process with each of the remaining four points (**Figure 3**). Through the calculation and averaging of the angular motions of each of the four line segments between two neck positions, the angular motion of the vertebra were yielded. To describe completely the vertebral motion in the sagittal plane, we also calculated the translation of the vertebra (**Figure 4**). The translational motion was defined

*Personal communication, Chuck O. OEC Medical Systems Distributor, CORE Medical Distributors; June 1999.

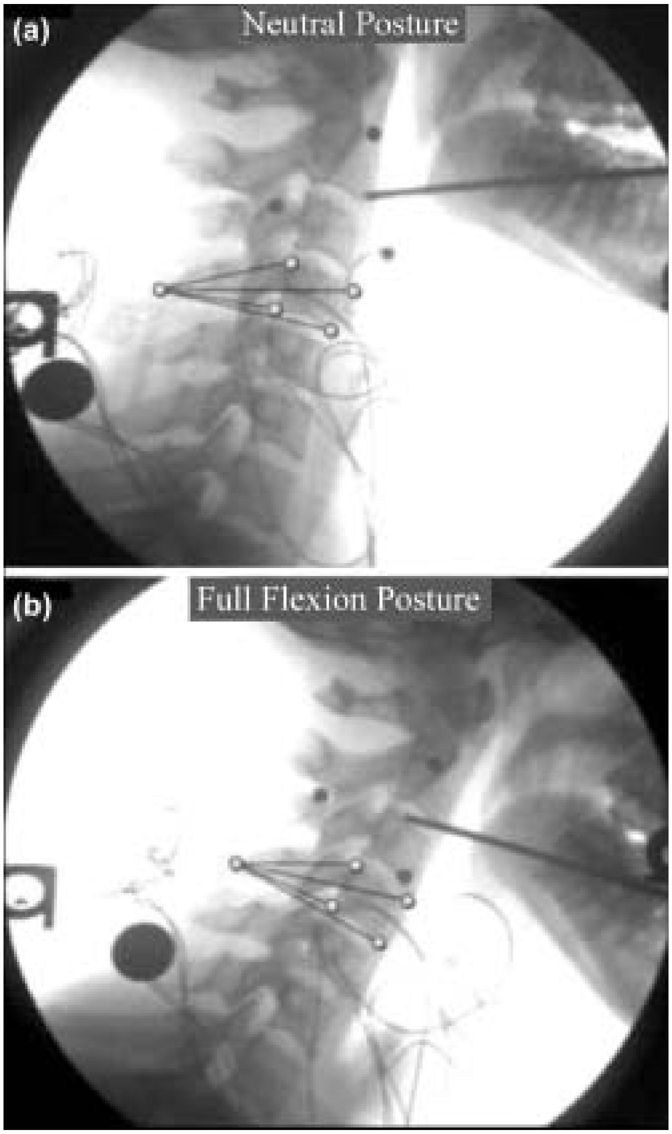

Figure 3.
Technique to calculate vertebral angular motion. **(a)** Digitization of C4 vertebra in neutral posture and **(b)** digitization of C4 vertebra in fully flexed posture. Angular motion of each of four line segments between two postures was first calculated. Then four angles were averaged to calculate angular motion of C4 vertebra from neutral to full-flexed posture.

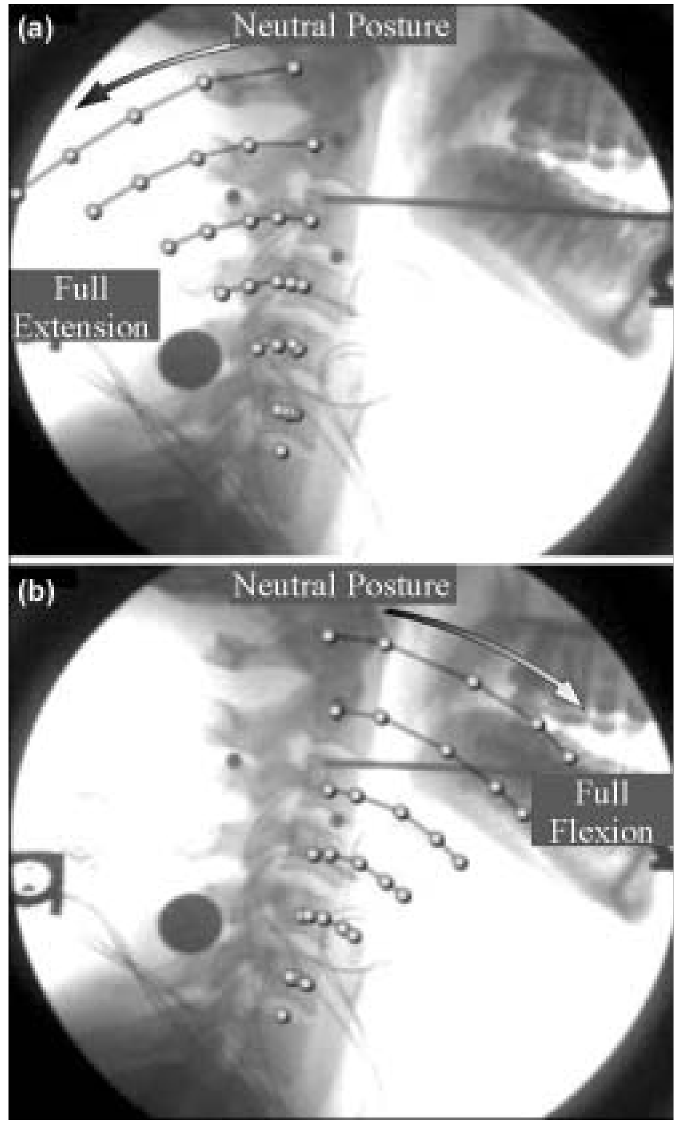

Figure 4.
Translational motion of each cervical vertebra in **(a)** extension and **(b)** flexion. VF allowed continuous tracking of cervical spine throughout complete range of motion. Centroidal motion was measured in millimeters.

as the motion of the centroid of the five digitized points (henceforth called "vertebral centroid"). We calculated the motion (angular and translational) at a given segment by subtracting the motion of the caudal vertebra from the cephalad vertebra of the motion segment.

Surface EMG data and Optotrak motion data were collected by a single computer, thus synchronized in time throughout the range of motion. The EMG data was rectified and filtered with the use of a cutoff frequency of 5 Hz. Next, we analyzed the EMG data. For flexion trials, we considered EMG signals from the sternocleidomastoid muscles. For extension trials, we considered EMG signals from the posterior cervical paraspinal muscles. First, we identified the EMG level of each subject, in the orthoses, that corresponded to the maximum angle in flexion and extension as measured by the optoelectronic method. Second, we identified the maximum EMG value for each subject during flexion and extension. For all subjects, the peak EMG value corresponded to the maximum flexion or extension angle. Therefore, we compared the maximum angular motion and maximum EMG values for flexion and extension between the four orthoses. EMG signals in subjects with orthoses were not compared to EMG signals in subjects without orthoses.

We calculated gross head motion relative to ground using the optoelectronic method. Also, we measured neck motion by measuring (1) the *angular* change of C0 relative to C7 on VF images, (2) intervertebral angular motion of C0 to C7, (3) gross translational motion of the neck C1 relative to C7 on VF images, and (4) intervertebral translational motion of C1 to C7.

To assess the reliability of the digitized measurements, we conducted a correlation analysis on two sets of measurements from two different observers. Two different observers randomly chose and digitized five subject files independently. The Pearson Correlation Coefficients for the digitized measurements were 0.95 for flexion angle data, 0.95 for extension angle data, and 0.99 for all angle data. Since the correlation between the two measurements is very close to 1.0, the task of digitizing files was divided between two different observers without affecting reliability of the calculated data.

To determine accuracy, we compared the optoelectronic data (C0 relative to the ground) to the calculated motion data from the digitized VF images. The Optotrak system has been factory-calibrated to provide an accuracy of ±0.1 mm for translational measurements and ±0.1° for rotational measurements. For maximum flexion angle data in all four orthoses, the average percent difference between the Optotrak data and the C0 data calculated from the VF digitized measurements was 8.8 percent. For maximum extension angle data in all four orthoses, the average percent difference was 1.6 percent. The combined (flexion and extension) average percent difference between the optoelectronic data and VF data was 3.8 percent. This means that there is a ±3.8 percent measurement error in the VF-digitized data (i.e., a VF measurement of 10° is accurate to within ±0.38°).

To assess the repeatability of the whole experimental protocol, we tested three subjects in flexion-extension while wearing four cervical orthoses (Miami J and Aspen collars, and Aspen 2-post and 4-post CTOs). These tests were performed on two separate occasions, at least 1 week apart. The Optotrak system was used to measure the gross motion of the head, and a correlation analysis was performed to compare the two separate trials of each subject for each of the four cervical orthoses. The average Pearson Correlation Coefficients were 0.95 for flexion angle data and 0.78 for extension angle data. The SAS (SAS Institute, Inc., Cary, North Carolina) statistical software package was used to perform a univariate analysis of variance (ANOVA), with Bonferroni adjustment on the post hoc tests for multiple comparisons.

RESULTS

Of the 20 subjects tested, 13 were included in the final data analysis. Seven subjects were excluded because of poor VF image quality.

EMG Signal Data

EMG signals were used to determine if there was a significant difference in subject effort between the two collars and between the two CTOs during flexion-extension motion. At the point of maximum flexion, no statistically significant differences were found between EMG signal values when comparing the Miami J and Aspen collars (0.12 mV versus 0.13 mV, $p = 0.7$) or when comparing the 2-post and 4-post CTOs (0.14 mV versus 0.14 mV, $p = 0.94$). Similarly, at maximum extension, no significant differences in the EMG signal were found between the two collars (0.03 mV versus 0.04 mV, $p = 0.64$) or between the two CTOs (0.05 mV versus 0.04 mV, $p = 0.53$).

Gross Head Motion Restriction

Each orthosis significantly reduced the gross head angular motion as measured by Optotrak relative to the ground in both flexion and extension ($p < 0.05$) (**Table 1**). Flexion motion allowed in the Miami J collar was significantly greater than that allowed in the Aspen collar ($p < 0.05$). No significant difference was found between the two collars in extension ($p < 0.05$). The Aspen 2-post CTO and 4-post CTO performed similarly in flexion, but a significant difference was found in extension ($p < 0.05$). When comparing the cervical collars versus the CTOs, we found significant differences between the groups in flexion and extension. The Aspen 4-post CTO outperformed all orthoses in limiting gross head motion.

Neck (C0 to C7) Motion Restriction

When measuring angular motion of C0 relative to C7 using VF images, we found no statistically significant differences in angular motion allowed between the

Table 1.
Gross head motion relative to ground allowed by each cervical thoracic orthosis (CTO) as a percentage of unrestricted motion. All motion percentages are statistically significant ($p < 0.05$). Significant differences between collars versus CTOs were found both in flexion and extension. Mean values and standard deviations are shown in parentheses.

Cervical Orthosis	Flexion	Extension
Unrestricted	100	100
Miami J Collar	40 (13)*	46 (15)†
Aspen Collar	31 (10)*	48 (19)†
2-Post CTO	16 (8)‡	39 (17)§
4-Post CTO	12 (6)‡	20 (13)§

*Miami J collar was significantly greater than that allowed in Aspen collar ($p < 0.05$).
†No significant differences were found between two collars.
‡No significant difference was found between two CTOs.
§A significant difference was found between two CTOs ($p < 0.05$).

Table 3.
Centroidal neck motion allowed by each cervical thoracic orthosis (CTO) (C1 relative to C7) as a percentage of unrestricted motion. All centroidal motion percentages are statistically significant ($p < 0.05$). Significant differences between collars versus CTOs were found in both flexion and extension. Mean values and standard deviations are shown in parentheses.

Cervical Orthosis	Flexion	Extension
Unrestricted	100	100
Miami J Collar*	50 (21)	61 (27)
Aspen Collar*	42 (18)	62 (31)
2-Post CTO	24 (15)†	50 (24)§
4-Post CTO	17 (10)†	24 (15)§

*No statistically significant differences were found between two collars in both flexion and extension.
†No significant difference was found between two CTOs.
§A significant difference was found between two CTOs ($p < 0.05$).

Miami J and Aspen collars in either flexion or extension. The Aspen 2-post CTO and 4-post CTO performed similarly in flexion, but a significant difference was found in extension ($p < 0.05$) (**Table 2**). When comparing the cervical collars versus the CTOs, we found significant differences between the groups in flexion and extension.

Each orthosis significantly reduced translational motion of the C1 centroid relative to C7 in both flexion and extension ($p < 0.05$) (**Table 3**). No statistically significant differences were found between the Miami J and Aspen collars in either flexion or extension. When comparing the Aspen 2-post CTO versus the Aspen 4-post CTO, we found no statistical difference in flexion, but we did find a significant difference in extension ($p < 0.05$). Comparison between the cervical collars and the CTOs yielded significant differences ($p < 0.05$) between the groups in flexion and extension. The Aspen 4-post CTO provided the most restriction of translational motion. The Aspen 4-post CTO was found to be the most effective orthosis in reducing motion in extension according to both measurement techniques.

Table 2.
Angular neck motion allowed by each cervical thoracic orthosis (CTO) (C0 relative to C7) as a percentage of unrestricted motion. All motion percentages are statistically significant ($p < 0.05$). Mean values and standard deviations are shown in parentheses.

Cervical Orthosis	Flexion	Extension
Unrestricted	100	100
Miami J Collar*	16 (24)	32 (29)
Aspen Collar*	18 (15)	43 (19)
2-Post CTO	–1 (18)†	38 (23)
4-Post CTO	–1 (14)†	22 (24)

*No statistical difference was allowed in flexion or extension motion between two collars ($p > 0.05$).
†No statistical difference was allowed between two CTOs ($p > 0.05$).

Intervertebral Angular Motion Restriction

Angular data for flexion revealed that all orthoses significantly reduced motion at all segments relative to unrestricted motion (two-tailed $p < 0.05$). No significant differences in flexion were allowed at any intervertebral segment between the Aspen or Miami J collars except at C5-6, where the Miami J allowed more motion (two tailed $p < 0.05$) (**Figure 5**). When comparing the capability of the 2-post and 4-post CTOs to restrict intervertebral angular motion, we found that the 4-post CTO provided significantly more restriction in flexion at the C3-4 level (two tailed $p < 0.05$). However, no other significant differences were found at other levels between the 2-post and 4-post CTOs. In restricting angular motion in flexion, the CTOs were significantly better than the collars at C3-4, C5-6, and C6-7 segments ($p < 0.05$) (**Figure 5**).

In general, all orthoses significantly reduced intervertebral angular motion in extension ($p < 0.05$) at all levels relative to the unrestricted motion. Few exceptions were found at C6-7, the collars did not significantly reduce ($p > 0.05$) extension angular motion, and at C1-2, no statistical difference ($p < 0.05$) was found between the 4-post CTO and unrestricted motion (**Figure 6**). No significant differences ($p > 0.05$) were found at any level in intervertebral angular motion restriction in extension

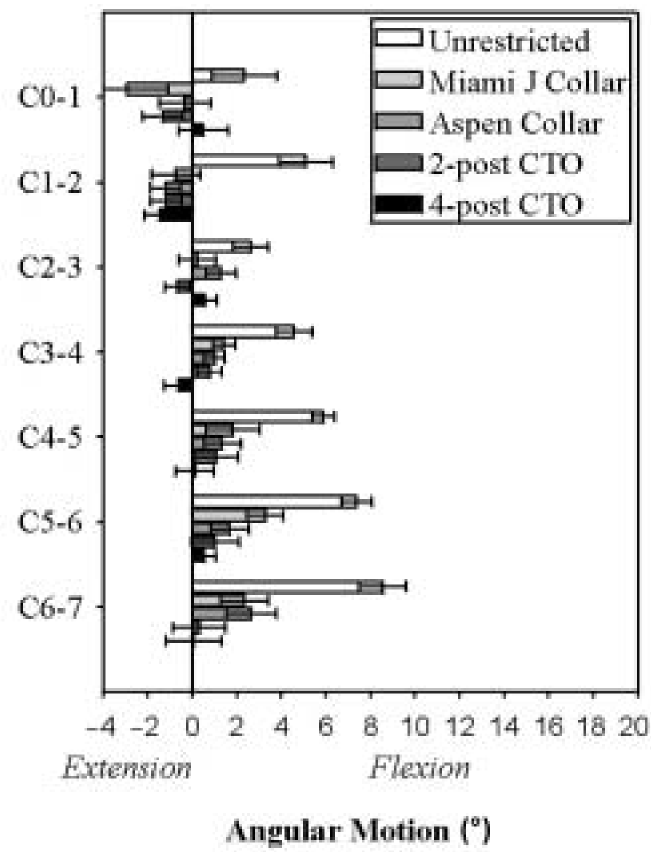

Figure 5.
Average angular motion at each cervical segment from neutral posture to *full flexion* posture. Mean values and standard error bars are shown. Evidence of snaking occurs at C1-2, where extension occurs despite head and neck being in a fully flexed posture.

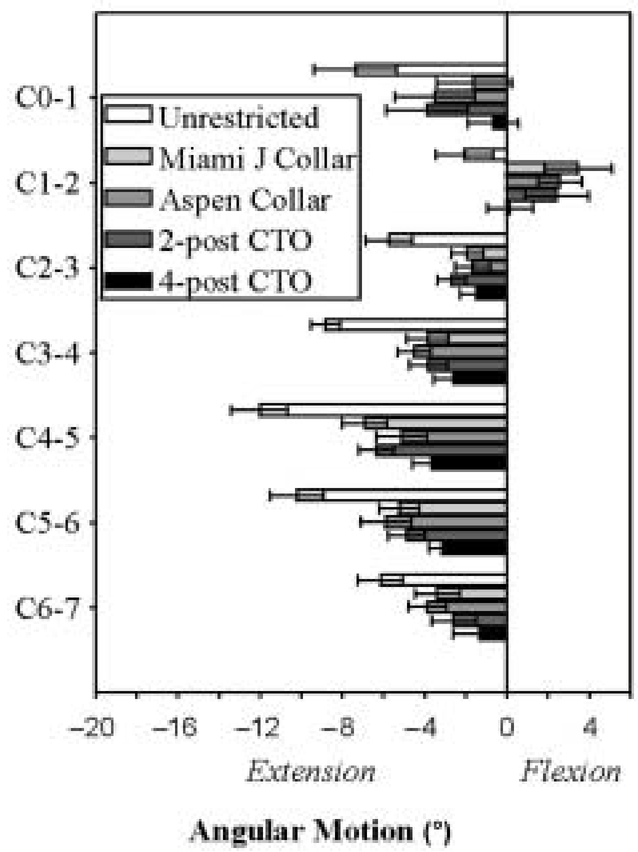

Figure 6.
Average angular motion at each cervical segment from neutral posture to *full extension* posture. Graph shows that 4-post CTO most effectively limited extension. Also evident is snaking that occurred at C1-2, where flexion occurred despite head and neck being in a fully extended posture.

between the Miami J and Aspen collars. The 4-post CTO was significantly better than the 2-post CTO in reducing angular motion in extension at segments C4-5 and C5-6. The 4-post CTO was significantly better than all other orthoses at restricting intervertebral angular extension at all cervical levels. No significant differences were found at any segment between the 2-post CTO and the collars in restricting angular extension motion.

Intercentroidal Translational Motion Restriction

Intercentroidal translational motion restriction in flexion and extension was defined as the difference between the translation of one vertebral centroid from an adjacent vertebral centroid relative to C7. Both CTOs significantly reduced intercentroidal translational motion versus both collars at all segments measured ($p < 0.05$). All orthoses significantly reduced intercentroidal translational motion at all levels in flexion versus no orthosis ($p < 0.05$). The Aspen collar provided significantly more restriction of intercentroidal motion in flexion at the C1-2 and C5-6 segments versus the Miami J collar. No significant differences were found in flexion at any level between the 2-post and 4-post CTO (**Figure 7**).

In extension, the CTOs were significantly more effective than the collars in reducing translational motion at all levels ($p < 0.05$) (**Figure 8**). All orthoses significantly reduced intercentroidal motion at all levels versus no orthosis ($p < 0.05$). No statistical differences were found at any level between the two collars in extension for intercentroidal translational motion. The 4-post CTO restricted the intercentroidal motion significantly better at all levels versus the 2-post CTO in extension. We did

Journal of Rehabilitation Research and Development Vol. 40, No. 6, 2003

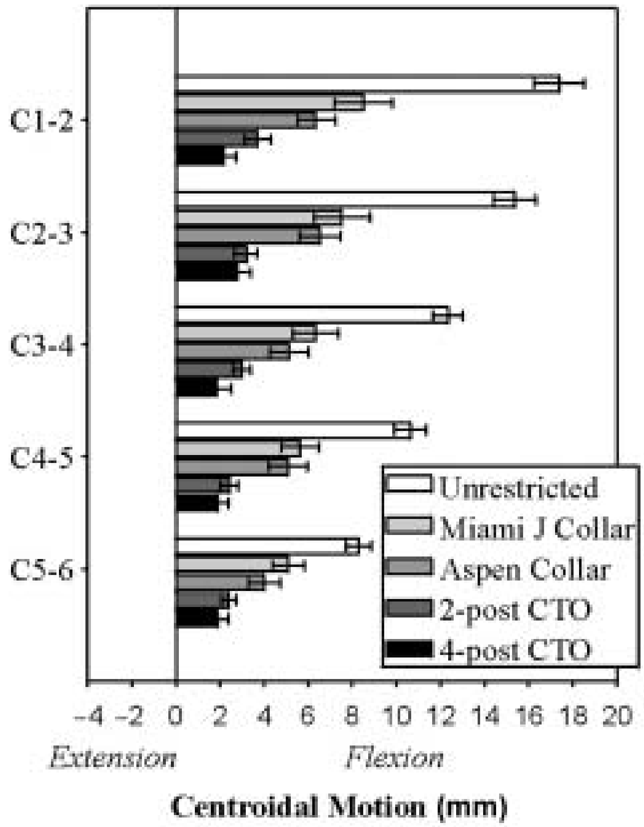

Figure 7.
Average intercentroidal translational motion relative to C7 from neutral posture to *full flexion* posture. Mean values and standard error bars are shown. These results show that translational motion allowed by two collars are similar, and translational motion allowed by two CTOs are similar.

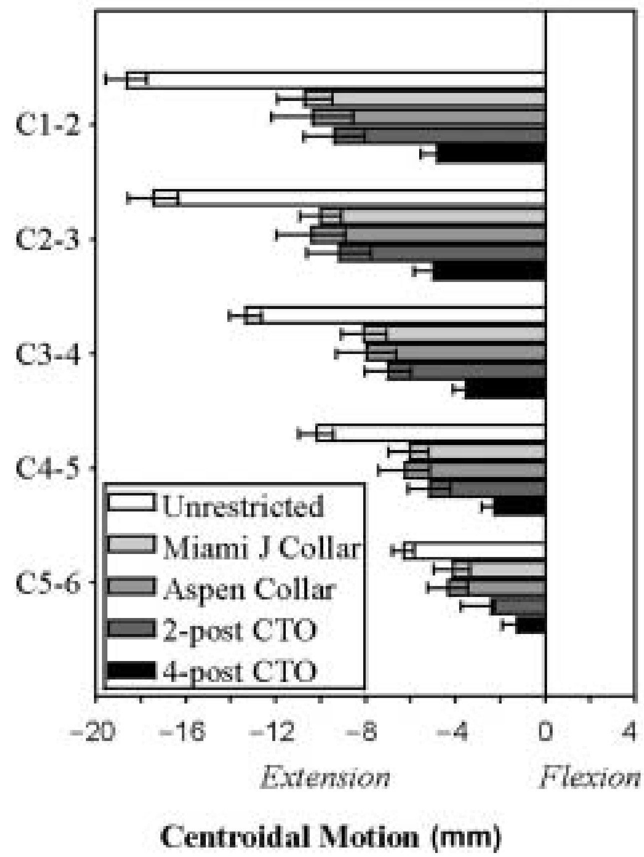

Figure 8.
Average intercentroidal translational motion relative to C7 from neutral posture to *full extension* posture. Mean values and standard error bars are shown. 4-post CTO appears to be most effective orthosis in reducing amount of translatory extension, especially in lower cervical segments.

not calculate the translational intervertebral data for the C6-7 segment because of our inability to digitize the inferior endplate of C7 in some of the subjects. Movement occurring opposite to the direction of neck motion, often referred to as “snaking,” was evident in the angular motion data, especially at C1-2 (**Figures 5** and **6**).

DISCUSSION

The amount of effort exerted by a subject during flexion-extension of the neck while wearing a cervical orthosis can influence the results. Fisher et al. used an infant sphygmomanometer bladder attached to a transducer and recorder in an attempt to control the amount of active force elicited by each subject when in an orthosis [10]. However, the placement of the bladder at the chin and the occiput may have altered the mechanical function of the orthosis by hindering total contact between the subject and the brace. Lunsford et al. controlled for passive force by attaching a 2.3 kg weight to a special helmet through a pulley system [11]. This study did not use a larger weight because of safety concerns to the patient and therefore did not give results for motion restriction under higher force conditions.

In the present study, we used EMG signals from the sternocleidomastoid and the cervical paraspinal muscles to compare motion allowed by each orthosis as a measure of the level of effort elicited by each subject. We believe that this allowed for a more accurate comparison between orthoses.

Previous studies that have quantified intervertebral motion have only looked at angular motion of vertebrae

[5,7,9]. The ability to limit translation of the vertebrae is particularly important in the cervical spine because excessive motion (instability) in the shear mode can potentially aggravate neurological problems. Thus, evaluating the angular motion alone can be misleading because it does not fully characterize the capability of a cervical orthosis to restrict the motion of cervical vertebrae. Furthermore, Chen noted that vertebral centroid measurement of lordosis is more reliable than angular measurement technique for assessing geometric changes in lordosis [14]. The vertebral endplate has a ridge that affects how a line is drawn upon it, thus affecting angular measurements [15]. Chernukha et al. suggested that the lateral projections of the vertebral endplate cannot be considered as straight lines and found that when using the Cobb measurement [16], an examiner could select a variety of lines drawn parallel to the lateral projection of the endplate. However, Chen's study did not investigate in vivo motion of the spine with orthoses.

The intervertebral angular motion and intercentroidal translational motion together provide a complete description of the cervical spine motion in the sagittal plane. For example, angular changes can occur in the neck simply through capital flexion and extension, similar to nodding the head. This movement can be accomplished with minimal translation of the head and neck over the thorax. Likewise, the head can be thrust forward in the horizontal plane, similar to "sticking one's neck out." This movement can be accomplished with minimal tilting of the head on the neck. Measurement of centroidal translation would allow distinction between these two types of movements. Centroidal technique could be employed as an adjunct method to measure intervertebral motion in orthoses. To our knowledge, no previous study has measured in vivo centroidal motion with subjects wearing orthoses.

We measured head angular motion in two ways: (1) the absolute angle of the head relative to the ground using an optoelectronic method (gross head motion) and (2) the relative motion between C0 and C7 measured using VF images. The C0 to C7 relative motion results revealed significantly smaller percentages of motion allowed ($p < 0.01$ for all devices in flexion and $p < 0.02$ for the collars in extension) versus the gross head motion measurement (**Table 2** versus **Table 1**). Gross head motion results revealed that the Aspen collar was significantly better at restricting motion versus the Miami J collar. However, gross head motion measurement may have incorporated motion occurring below the cervical spine despite our subjects being carefully restricted in a custom-built harness, whereas the C0 to C7 relative motion measurement isolated pure cervical spine motion. Since cervical orthoses are designed to restrict the motion occurring between cervical vertebrae, our observations suggest that a radiographic technique provides a more accurate assessment of the performance of these devices.

Sharpe et al. who evaluated the performance of the USMC CTO design using the traditional radiographic endplate measurement technique found that it restricted both flexion and extension to 22 percent of unrestricted motion [7]. The results of the present study showed the Aspen 4-post CTO restricted flexion to 1 percent (±8%) of unrestrained motion and extension to 23 percent (±19%) (**Table 2**). Johnson et al. noted that increasing the rigidity and length of the orthosis was correlated with the overall capability to restrict flexion and extension motion of the cervical spine [9]. This finding was confirmed by our data that showed the Aspen 2-post and 4-post CTOs, both of which have thoracic extensions, generally outperformed cervical orthoses in both flexion and extension. The superior motion limitation achieved with a 4-poster, which has two posterior uprights to provide additional extension stability, may indicate the necessity of a posterior support to help control for extension. However, viewing each category of orthoses, collars, and CTOs, separately may be more helpful.

In a recent radiographic study, Askins and Eismont found that the Aspen collar allowed 41 and 36 percent of unrestricted angular C0 to C7 motion in flexion and extension respectively [5], while the Miami J only allowed 24 and 30 percent for the same modes of motion—a difference that was statistically significant. In the present study, we found no statistical difference when comparing the effectiveness of the Miami J and Aspen collars in restricting C0 to C7 motion (**Table 2**). We believe that in the present study, the use of a certified orthotist, who was experienced in the custom-fitting of all of the cervical devices, may have played a role in obtaining results contrary to previous research. It is also possible that changes in the design of the Miami J or Aspen collars that have occurred since previous studies may have altered their biomechanical behavior. Both 2-post and 4-post CTOs performed similarly in flexion, but the addition of posterior uprights in the 4-post CTO increased its flexion restriction slightly and extension restriction capability substantially (**Table 1**). The presence of posterior uprights appears to be a prerequisite for an orthosis to effectively limit extension. The capability of the 4-post CTO to effectively restrict extension motion seems to contradict the current thinking that the halo may be the only effective orthosis for reducing motion in extension.

The intervertebral angular motion data revealed that irregular motion occurred in the upper cervical spine (C1-2) while subjects were in flexion and extension in all orthoses, (**Figures 5** to **8**). For example, as the subjects fully flexed the neck while wearing an orthosis (**Figure 5**), the C1-2 segment underwent angular motion in extension. Similarly, as the subjects fully extended the neck in an orthosis (**Figure 6**), the C1-2 segment underwent angular motion in flexion. This phenomenon, sometimes called “snaking,” as we mentioned before, has been observed in previous studies [7,9]. The VF technique enabled us to measure angular motion at each cervical segment *between* the neutral and maximum flexed or extended positions. We observed in some cases that “normal” motion occurred to a point in these segments in the early stages of flexion-extension, but as the resistance of the orthosis increased and the subject increased his or her effort, the snaking phenomenon, or “reverse vertebral tilt” would occur (**Figure 9**). We believe that the end point radiographic angular measurement technique is misleading in a segment where snaking is evident because it represents only one point in time. VF has shown us that motion can occur before this end point that is not picked up by end point radiographic technique (**Figure 9**). Furthermore, we believe snaking can contribute to inaccuracies in angular measurement as evidenced by the lack of significant differences in intervertebral measurements in our angular data. With future VF studies, investigators may find that identifying the points of maximum flexion and extension a segment experiences *during* a range of motion versus the end point measurements to determine true range of motion restriction in orthoses.

The study had some limitations. We measured only active voluntary motion in each subject. They were instructed to flex or extend as far as possible. It is possible that greater ranges of motion could be recorded passively, but we felt it was not worth the risk of injuring a healthy subject. Measurements were only recorded and analyzed for motion occurring in the sagittal plane. Recommendations for orthotic stabilization for coronal or transverse instabilities cannot be made based on the results of this study. Our study only investigated cervical orthoses on normal healthy subjects. It is unclear if the results in normal subjects are applicable to those with cervical injury. This study did not investigate the issues

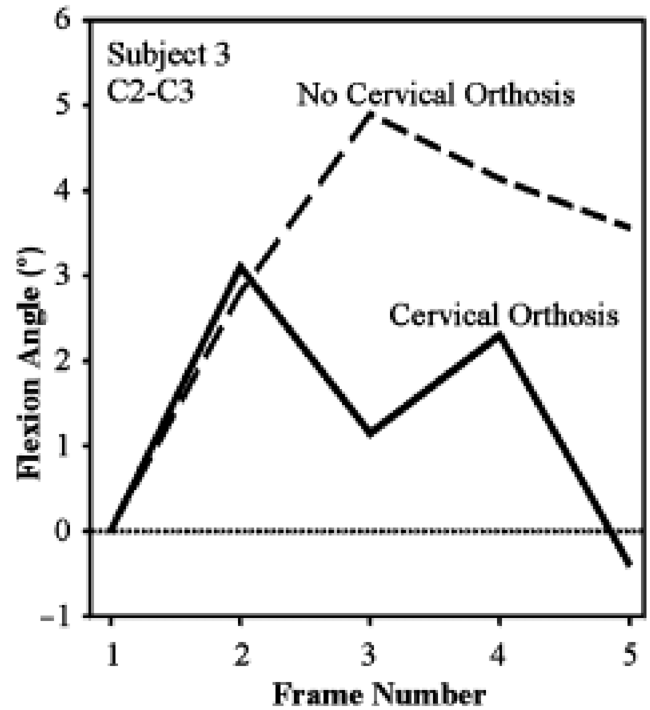

Figure 9.
Limitation of end point radiographic technique. Using end point radiographic technique to measure orthosis restriction of motion can be misleading. Frame 1 represents neutral posture, while Frame 5 represents full flexion posture. Solid line represents flexion angle for one subject who flexed forward while wearing a cervical orthosis; dotted line represents flexion angle for same subject while wearing no orthosis. With subject wearing an orthosis, point of maximum flexion occurs in Frame 2, despite end point data (Frame 5) being in extension. Selecting this point to determine true flexion or extension range that can occur in an orthosis may be more appropriate.

of comfort or compliance of subjects in wearing cervical orthoses. Investigation of these issues would enhance the orthosis selection process.

CONCLUSIONS

The results of this study provide objective data to help the medical practitioner choose the appropriate cervical device for nonoperative and postoperative use and to offer an alternative methodology to measure motion restriction effectiveness of cervical orthoses. Shimamoto et al. recommended that a cervical interbody fusion cage at C4-5 should be supplemented with additional external or internal supports to prevent excessive motion that occurs adjacent to that segment in flexion and extension

[17]. The Aspen 4-post CTO restricted the motion around this segment the best and would be the most effective candidate of the orthoses tested to prevent this motion in flexion and extension. The Aspen 2-post CTO restricted flexion motion effectively below C2 and may pose as an acceptable alternative to the SOMI, an orthosis commonly used to prevent flexion. Mean percent of normal motion allowed was 1 ± 18 percent for the Aspen 2 post CTO as compared to 7.2 ± 4.6 percent for the SOMI in Johnson et al.'s study [9].

The Miami J and Aspen collars were statistically similar in their capability to provide intersegmental motion limitation in flexion and extension, with the exception at C5-6. At this level, the Aspen collar restricted flexion better than the Miami J according to both our centroidal and angular intersegmental measurement techniques. Our findings suggest that either of the two collars could be used to treat similar cervical pathologies or injuries except those involving the C5-6 segment, where the Aspen collar may provide better motion restriction.

This study looked at normal healthy subjects. Injured subjects most likely would not exert the maximal effort elicited by the subjects in this study. However, there are higher risk situations where the physician may want to protect a patient from excessive cervical motion such as trauma, noncompliance, unconsciousness, or seizures.

Our study highlights the importance of testing new and updated versions of cervical orthoses and the necessity of customized fitting of prefabricated devices. Future studies should consider centroidal measurement as an adjunctive method to assess motion restriction capability of cervical orthosis. In addition, the use of VF or X-ray technology may allow a more accurate assessment of cervical motion restriction.

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