A 3D motion analysis study comparing the effectiveness of cervical spine orthoses at restricting spinal motion through physiological ranges

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Abstract

Objective To compare the effectiveness of the Aspen, Aspen Vista, Philadelphia, Miami-J and Miami-J Advanced collars at restricting cervical spine movement in the sagittal, coronal and axial planes.

Methods Nineteen healthy volunteers (12 female, 7 male) were recruited to the study. Collars were fitted by an approved physiotherapist. Eight ProReflex (Qualisys, Sweden) infrared cameras were used to track the movement of retro-reflective marker clusters placed in predetermined positions on the head and trunk. 3D kinematic data were collected during forward flexion, extension, lateral bending and axial rotation from uncollared to collared subjects. The physiological range of motion in the three planes was analysed using the Qualisys Track Manager System.

Results The Aspen and Philadelphia were significantly more effective at restricting flexion/extension than the Vista ($p < 0.001$), Miami-J ($p < 0.001$ and $p < 0.01$) and Miami-J Advanced ($p < 0.01$ and $p < 0.05$). The Aspen was significantly more effective at restricting rotation than the Vista ($p < 0.001$) and the Miami-J ($p < 0.05$). The Vista was significantly the least effective collar at restricting lateral bending ($p < 0.001$).

Conclusion Our motion analysis study found the Aspen collar to be superior to the other collars when measuring restriction of movement of the cervical spine in all planes, particularly the sagittal and transverse planes, while the Aspen Vista was the least effective collar.

Keywords 3D motion analysis · Cervical spine · Kinematics · Cervical orthoses

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Introduction

Cervical orthoses are used in the management of patients following cervical spine injury or surgery to provide stability and protection to the spinal cord by reducing spinal motion. Although a number of orthoses are commercially available, there is currently no consensus as to which offers the greatest protection, with studies showing considerable variation in cervical orthoses ability to restrict motion [1–4]. Assessing the effectiveness of cervical orthoses at restricting spinal motion has historically proved challenging due to a relatively poor understanding of cervical spine kinematics and the difficulty in accurately measuring spinal motion. Radiographic methods (plain film radiography, cineradiography, video fluoroscopy, computerised tomography and magnetic resonance imaging) are costly, time consuming and expose subjects to unacceptable levels of

ionising radiation while there are concerns regarding the reliability and reproducibility of the data using non-radiographic methods (video, inclinometry, electrogoniometry and stereophotography), but the fundamental limitation of most of these techniques is with the two dimensional measurement of cervical spine motion. Motion analysis systems allow spinal movement to be measured in three dimensions but only a few studies have utilised this technology to compare the effectiveness of cervical orthoses at restricting motion [1, 2, 5, 6].

This study compares the effectiveness of the Aspen, Aspen Vista, Miami-J, Miami-J Advanced and Philadelphia collars in restricting cervical spine movements through physiological ranges using a three-dimensional kinematic motion analysis system incorporating optoelectronic passive marker and video-based technology. The Aspen Vista and Miami-J Advanced collars are adjustable one-collar-fits-all designs that have recently been marketed. There is currently no literature available on their ability to restrict cervical spine motion relative to their respective standard designs. This is the first study to use this design of motion analysis system to compare the effectiveness of these orthoses in restricting cervical spine motion.

Materials and methods

The research was conducted in the Motion Analysis Laboratory at the Cardiff School of Engineering. Eight Qualisys (Sweden) ProReflex Motion Capture Units (MCU) and two video cameras were strategically positioned around the

subject (Fig. 1). Each MCU emitted infra-red light which was reflected by retro-reflective body markers and detected by the MCUs scanning the field of view sixty times per second (60 Hz). The Qualisys Track Manager (QTM) software system enabled all the markers to be tracked in three-dimensions for any movement of interest. The 6-degrees-of-freedom (6DOF) tracking function provided 6DOF data from any user-defined rigid body providing information on the rotational and translational movements of a moving body. The head and trunk rigid bodies were defined using marker clusters. The markers on each cluster were orientated and positioned such that the geometric centre of each cluster within a global coordinate system could be determined. One marker cluster was placed in the midline of the head, in line with the external auditory meatus, to define the head rigid body and a second marker cluster was placed in the midline of the back, 15 cm below the T1 spinous process, to define the trunk rigid body (Fig. 2). The markers were converted to a three dimensional image using the QTM software and the head and trunk rigid bodies defined such that their movements could be described relative to each other; this movement reflecting gross motion of the cervical spine.

Nineteen healthy volunteers, with no known history of spinal injury and no previous spinal pathology, were recruited. Exclusion criteria included subjects less than 18 years of age and greater than 40 years of age. A neutral starting position was adopted and subjects were asked to perform a set sequence of movements (forward flexion, extension, left rotation, right rotation, left lateral bend, right lateral bend) to their maximal ability without a collar, returning to the neutral position between each movement. Collars were chosen by double blind

Fig. 1 Cardiff motion analysis laboratory

Fig. 2 Marker positioning (anterior, lateral and posterior views)

Table 1 Mean physiological range of movement in the three planes in different collars

Movement	No collar	Aspen	Philadelphia	Vista	Miami-J	Miami-J Advanced
Flexion/extension	127.4 (14.0) ^a	29.9 (12.2) ^{bc}	31.3 (11.4) ^d	39.8 (9.4)	38.3 (11.6)	37.7 (12.5)
Rotation	150.3 (15.9) ^a	37.6 (15.8) ^b	45.8 (20.5)	52.2 (13.8)	48.3 (17.1)	45.9 (19.8)
Lateral bend	81.5 (14.5) ^a	35.6 (11.8) ^e	39.9 (11.9) ^f	53.4 (10.7)	41.4 (15.6) ^h	39.2 (14.1) ^g

Standard deviation shown in brackets

^a No collar vs. collars ($p < 0.001$)

^b Aspen vs. Vista ($p < 0.01$)

^c Aspen vs. Miami-J ($p < 0.05$)

^d Philadelphia vs. Vista ($p < 0.05$)

^e Aspen vs. Vista ($p < 0.001$)

^f Philadelphia vs. Vista ($p < 0.01$)

^g Advanced vs. Vista ($p < 0.01$)

^h Miami-J vs. Vista ($p < 0.05$)

random selection and fitted by an approved physiotherapist. Subjects were asked to perform the same sequence of movements to their maximal ability without distorting the collars. The GraphPad InStat (Version 3.10) software package was used to perform statistical analysis of the data. A one-way repeated measures ANOVA and Tukey post hoc comparison test was used to compare the ranges of movement and percentage restriction in movement between the different collars. Error bars represent 95 % confidence intervals.

Results

Nineteen subjects (7 male, 12 female) participated in the study. The mean age of the subjects was 29 ± 5 years

(range 18–38 years). The mean body mass index of the subjects was $23.3 \pm 3.1 \text{ kg/m}^2$ (range 18.3–29.9 kg/m^2). Movements in the sagittal, transverse and coronal planes were restricted by the application of a collar ($p < 0.001$). The mean physiological range of movement and the percentage restriction of movement in each plane were compared between individual collars (Table 1; Fig. 3). In the sagittal plane, the Aspen collar was the most effective at restricting flexion/extension. Both the Aspen and Philadelphia collars were significantly more effective than the Vista ($p < 0.001$), Miami-J ($p < 0.001$ and $p < 0.01$, respectively) and Miami-J Advanced ($p < 0.01$ and $p < 0.05$, respectively) collars at restricting movement in this plane. The Aspen collar restricted movement in this plane by 76.4 % compared to the Vista (68.5 %), Miami-J (69.8 %),

Fig. 3 A comparison of percentage restriction to physiological range of movement by each collar in the three planes (error bars represent 95 % confidence intervals). ^aAspen versus Vista/Miami-J ($p < 0.001$), ^bAspen versus Advanced ($p < 0.01$), ^cPhiladelphia versus Vista ($p < 0.001$), ^dPhiladelphia versus Miami-J ($p < 0.01$), ^ePhiladelphia versus Advanced ($p < 0.05$), ^fAspen versus Vista ($p < 0.001$), ^gAspen versus Miami-J ($p < 0.05$), ^hVista versus Aspen/Philadelphia/Miami-J/Advanced ($p < 0.001$)

Miami-J Advanced (70.2 %) and Philadelphia (75.1 %) collars. In the transverse plane, the Aspen collar was the most effective at restricting rotation and was significantly more effective than the Vista ($p < 0.001$) and Miami-J ($p < 0.05$) collars at restricting movement in this plane. The Aspen restricted rotation by 75.1 % compared to the Vista (65.0 %), Miami-J (68.0 %), Miami-J Advanced (69.6 %) and Philadelphia (69.3 %) collars. In the coronal plane, the Aspen collar was the most effective at restricting lateral bending movements. It restricted movement in this plane by 54.4 % compared to the Vista (32.9 %), Miami-J (48.4 %), Philadelphia (49.0 %) and Miami-J Advanced (50.1 %) collars. The Vista collar was the least effective at restricting lateral bend and was significantly less effective than all the other collars ($p < 0.001$).

Discussion

Plain film radiography [7, 8], cineradiography [9, 10], videofluoroscopy [11], computerised tomography [12], magnetic resonance imaging [13], video and electromyography [14], digital inclinometry [15], stereophotogrammetry [16], electrogoniometry [17] and motion analysis systems [1–3, 18, 19] have been used to measure cervical spine motion. Each has their advantages and disadvantages, but the fact that so many techniques and systems exist suggests that the optimal method to measure cervical spine motion has yet to be found. The optoelectronic passive marker system used in this study provides a novel means of obtaining three dimensional kinematic data of the cervical spine. It utilises eight high frequency cameras to track retro-reflective skin markers and, by incorporating the QTM software, can accurately, reliably and safely describe the movement of these markers in 6DOF. There is currently no published literature using such a system to compare the range of cervical spine motion in different cervical orthoses.

The results from this study demonstrate that flexion/extension and rotational movements were more effectively restricted than lateral bending movements in all collars. The Aspen and Philadelphia collars were superior to the Aspen Vista, Miami-J and Miami-J Advanced collars at restricting flexion/extension. The Aspen collar was superior to the Aspen Vista and Miami-J collars at restricting rotation. The Aspen Vista collar was inferior to all the other collars at restricting lateral bending movements while the Aspen collar appeared to be the most effective at restricting movement in this plane. This study demonstrates that the effectiveness of the Aspen collar in restricting physiological ranges of movement was superior to the other collars, with the Philadelphia collar also performing well. The Aspen Vista collar was consistently less effective than the other collars at restricting the cervical spine through physiological ranges of movement, a finding that may be attributable to its one-size-fits-all design. The Miami-J and Miami-J Advanced collars were comparable at restricting movement.

Despite the findings, we acknowledge that limitations do exist with this study. The ideal motion analysis system would accurately locate the position of each cervical vertebra so as to assess movement at individual cervical motion segments, but this is complicated by the fact that the only palpable bony landmarks in the cervical spine are the spinous processes, and that those of C1 to C6 are concealed by the overlying ligamentum nuchae. Unless a radiographic technique is used, there is no reliable means by which to accurately identify each cervical motion segment. Motion analysis systems have therefore employed techniques to measure gross movement of the cervical spine. Some studies have used the occiput, to represent the C1 vertebra, and the spinous process of C7 as a model for determining gross cervical spine motion. While anatomically more accurate, the application of collars in this study prevented the use of these landmarks and consequently

marker positioning was determined by the proximal and distal extent of the collar. The nasion and external auditory meatus were felt to be reliable anatomical landmarks that could be readily defined on each subject. The head marker cluster was positioned in relation to these and used to define the orientation of the head in space. The T1 vertebral spinous process, being consistently the most prominent spinal process, was used as a landmark for the back marker cluster. This was positioned as close to the T1 spinous process as possible so as not to be impeded by the collar, a position 15 cm distal to it. By positioning the markers here, it meant that gross cervical spine movement would include an unavoidable contribution from the upper thoracic spine, although it was felt that this probably did not influence the results much.

The accuracy of passive marker systems in defining spinal motion has also been questioned. The positioning of markers on to bony landmarks is thought to be subject to observer bias, while the interposing soft tissue between the markers and bony landmarks is thought to create movement artefact. In an effort to minimise observer bias, the bony landmarks used were readily palpable and easily identifiable, and marker placement was conducted by the same person. The back cluster marker was a particular concern as it had to be removed each time during collar application. In order to minimise any potential error on repositioning the cluster, its position and orientation were marked prior to its removal. Unwanted movement of the head markers was minimised using a specially designed Velcro headband to which the marker cluster was applied. Long hair was tied back and kept in place with a hair net and clips. While this particular system has not been validated, Gracovetsky et al. [20] used a similar optoelectronic passive marker system to assess movement in the lumbar spine. They found that the results were consistent and comparable to radiographic measurements and concluded that it was possible to accurately measure spinal motion using such a system.

Cervical spine motion has been shown to be influenced by the age, gender, weight and athletic ability of an individual [21, 22]. A reduced range of motion has been associated with an increase in age and body weight, a decrease in athletic ability and in males over the age of 70 years. In order to measure maximal ranges of cervical motion, an attempt was made to choose subjects that reflected a normal healthy population so that a Gaussian distribution could be assumed. Subjects of both sexes, with no known history of spinal pathology or injury, were recruited to the study. All subjects were over the age of 18 years, and therefore skeletally mature, and under the age of 38 years. 68 % of the subjects were within the normal weight range as calculated using the BMI. The remaining subjects were either underweight or overweight. No obese subjects participated in the study and the majority

of subjects were athletic. A sample size of nineteen was used for the study, although not large, it was comparable to the sample sizes used in similar studies in the published literature [1, 3, 4]. A larger sample size would have increased the power of the study and the reliability of the data but our sample size was sufficient to perform statistical analysis. However, while statistical significance has been found in the data comparing the effectiveness of cervical orthoses, it is difficult to ascertain whether these differences are clinically significant. The Aspen collar permits on average 29.9° of flexion/extension through a physiological range, but is this clinically important? If the same collar allowed a further 10° of movement would this adversely affect the clinical outcome? If there is no deleterious effect on the clinical outcome, do the differences observed between the collars really matter? These questions are all hypothetical and this study does not attempt to answer them, but they are certainly worth considering when interpreting the statistical findings. While stability is fundamental in the design of cervical orthoses, additional factors such as comfort, ease of application and airway accessibility are equally important. Although a collar may provide exceptional stability, if it is uncomfortable to wear then non-compliance becomes an issue. Similarly, a collar that is difficult to apply may result in it being poorly fitted. These features need to be taken into consideration in the design of cervical orthoses.

Finally, it should be noted that cervical orthoses are not the only means of restricting spinal motion. Halo jacket application and surgical fixation are both recognised techniques of stabilising the cervical spine following injury but have their own inherent complications due to the invasiveness of the procedures. A study by Johnson et al. [7] has suggested that halo application is more effective at restricting motion than conventional bracing. The motion analysis technology used in this study could in future be used to compare the effectiveness of these techniques at restricting cervical spine motion and may provide useful information that could facilitate the decision-making process when determining whether cervical spine injuries should be managed operatively or non-operatively.

Conclusions

Flexion/extension and rotational movements of the cervical spine were more effectively restricted than lateral bending movements by all collars. The Aspen was the most effective collar at restricting movement in all three planes through physiological ranges. The Philadelphia collar was effective at restricting flexion/extension movements. The Aspen Vista was the least effective collar at restricting movement in all three planes through physiological ranges.

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