Efficacy of orthotic immobilization of the unstable subaxial cervical spine of the elderly patient: investigation in a cadaver model

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Objective: To assess the efficacy of soft, semirigid and hard cervical collars to immobilize the neck in a destabilized cadaver model. **Design:** This is a laboratory experiment. **Setting:** The anatomy research lab of McMaster University. **Patients:** None. Fresh cadavers from elderly patients suffering terminal medical illness and free of cervical structural disease were studied. **Interventions:** Destabilizing discoligamentous lesions of the neck were created in the cadavers. Radiographs were taken in maximum displacement in the prone, decubitus and side-bending positions, first unsupported and then with soft, semirigid and hard collars applied. Displacements in angulation and translation were measured from the radiographs. **Outcome measures:** Radiographic displacement under gravity load. **Results:** In all cases there was no effective limitation of pathological displacement, and in many cases displacement was increased after collar application. **Conclusions:** Cervical collars do not effectively support the unstable neck, and may be ineffective in preventing pathological displacements.

Objectif : Évaluer l'efficacité de minerves souples, semi-rigides et rigides pour immobiliser le cou sur un modèle de cadavre déstabilisé. **Conception :** Expérience de laboratoire. **Contexte :** Le laboratoire de recherche en anatomie de l'Université McMaster. **Patients :** Aucun. On a étudié des cadavres frais de patients âgés atteints de maladies terminales et qui n'avaient pas de maladie des structures cervicales. **Interventions :** On a produit chez les cadavres des lésions discoligamenteuses déstabilisantes du cou. On a pris des radiographies en déplacement maximal en pronation, supination et flexion latérale, d'abord sans support et ensuite avec minerve souple, semi-rigide et rigide. On a mesuré les déplacements angulaires et axiaux à partir des radiographies. **Mesures de résultats :** Déplacement radiographique sous charge naturelle. **Résultats :** Dans tous les cas, il n'y a eu aucune limitation réelle du déplacement pathologique et dans nombre de cas, la minerve a aggravé le déplacement. **Conclusions :** Les minerves n'appuient pas efficacement le cou instable et peuvent être inefficaces pour prévenir les déplacements pathologiques.

Injuries to the cervical spine are among the most devastating sequelae of blunt and penetrating trauma.[1,2] Routine 3-view plain radiographs are well recognized as being inexact in delineating these injuries, potentially failing to detect up to 15% of them.[3–7] Radiographic assessment of soft-tissue swelling is also known to be imperfect in delineating evidence of injury.[8–10] Computed tomographic images are more accurate in detecting bony trauma but do not generally detect discoligamentous trauma without fracture.[3,11,12] The role of the acute magnetic resonance imaging examination remains to be defined.[13,14]

Flexion–extension x-rays may be helpful in detecting radio-occult trauma but have poor sensitivity,[15,16] and may carry potential for injury of unconscious patients. The in-line traction test is well described in principle,[17] but remains rarely reported[18,19] and uncommonly practised.

Data have suggested that significant cervical structural injury in the conscious patient does not present without pain.[20–22] Accordingly, it is becoming routine in many trauma units to "protect the neck" in a rigid cervical orthosis until unconscious patients revive sufficiently to cooperate in their clinical examination. Such practice can lead to prolonged periods of orthotic immo-

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bilization in the obtunded or sedated trauma patient, limiting access to the neck for central line and tracheostomy care, and having potential for excoriation or ulceration of the skin through contact irritation with the orthosis.

Biomechanical studies have suggested that rigid cervical orthoses may be less than completely effective in restricting range of motion in the neck as assessed in normal controls, providing little more support than soft collars.[23–28] Accordingly, there is some question as to whether the unstable cervical spine can be adequately protected with these devices.

We have addressed this question in a cadaver study.

Materials and method

Six fresh adult cadavers of elderly patients who had died of medical disease were stored in a cool locker without freezing, to preserve normal tissue pliability as well as possible. Confidentiality in the postmortem donor program prevented our knowing the exact age of our specimens; all were very elderly and had significant dorsal kyphosis with corresponding ventral offset of the neck (not quantified). The cadavers were studied at least 48 hours post-mortem so as to exclude the potential immobilizing effects of rigor mortis, and not more than 5 days after death. Biplane primary screening radiographs were taken to exclude any disqualifying baseline pathology such as a tumour, fracture or arthritic instability.

Surgical lesions were created distal to C4, consistent with the recognized low subaxial location of most radio-occult injuries,[1,9] and above C6 so as to facilitate optimal radiographic visualization (Table 1).

First, a wide exposure of the posterior elements from C2 to T1 was obtained via a standard midline posterior approach. Initially, incomplete discoligamentous lesions were created posteriorly by sectioning of the supraspinous and interspinous ligaments, ligamentum flavum, facet capsular ligaments, spinal cord, posterior longitudinal ligament and posterior half of the disc. The skin wound was then temporarily sutured.

Extreme flexion stress was modelled by elevating the torso of the prone cadaver such that the weight of the head was unsupported other than by the neck. A lateral radiograph was then taken as an internal control, to assess flexural instability of the primary surgical lesion. The head was then manually returned to neutral alignment with the trunk. The cadaver was fitted sequentially with a soft wraparound Velcro cervical collar (Soft-Straight Collar, medium density; Zimmer USA), a semirigid Philadelphia collar (Zimmer USA) and then a rigid plastic transport collar (Stif-Neck Collar; Leardal Medical Corporation, Wappingers Falls, NY), released from support, and x-rayed again with each of the devices applied. Since the full range of small, medium and large sizes of each of the collars was at hand, the fitting was optimized for each experiment.

The torso was then turned on its side, with the head again unsupported other than by the neck, to create an extreme side-bending stress. Anteroposterior (AP) radiographs were taken to assess lateral instability. The sequence of collar-support options was again applied and AP radiographs recorded.

In the last set, the cadaver was turned supine and the unsupported head allowed to extend. X-ray images were recorded in the lateral projection. The cadaver heads were then supported sequentially in each of the 3 collars and radiographed.

As a second stage of this investigation, we reopened the posterior surgical wound and completely destabilized the index motion segment by transecting the remaining anterior half of the disc and the anterior longitudinal ligament. After skin closure, the sequence of unsupported and collar-restrained images in all 3 positions (prone, decubitus and supine) was repeated.

As a final series, we again reopened the posterior surgical wound and passed heavy Vicryl™ sutures around the posterior elements (laminas and spinous processes) of the index motion segment, effectively converting it to an anterior/middle column disruption model. After skin closure, the sequence of unsupported and collar-restrained postures in all 3 positions were again repeated and appropriate images obtained.

Angulation, translation and distraction of the index motion segment were measured directly from radiographs and recorded. Some data points are lacking because some films were over-penetrated too much to allow accurate measurement.

In the lateral views, angulation was measured as the angle between the planes of the lower endplates above and below the surgical site. Distraction and displacement were recorded with reference to the posteroinferior corner of the vertebra above to the posterosuperior corner of that below, normalized or orthogonal to the plane of the infrajacent lower end-plate.

In the AP view, angulation was taken as the angle between the adjacent end-plates across the index segment. Displacement and distraction referenced the superolateral corner of the lateral mass below the destabilization to the inferolateral corner of the lateral mass above, normalized or orthogonal to the lower end-plate above.

Our limited sample size argues for the presentation of raw data rather than pooled information; but given the relative preponderance of flexural injuries and angulatory/translational instability encountered in clinical practice,[29,30] we have presented our averaged data as well.

Table 1

Destabilization levels: cervical injury locations in 6 cadavers

1	2	3	4	5	6
C4/5	C5/6	C4/5	C3/4	C4/5	C4/5

Table 2

Angulation, translation & distraction in cadavers, in 3 destabilization models and 3 types of cervical collar

Stress mode & support	Cadaver 1			Cadaver 2			Cadaver 3			Cadaver 4			Cadaver 5			Cadaver 6		
	A	T	D	A	T	D	A	T	D	A	T	D	A	T	D	A	T	D
Destabilization of posterior columns only																		
Flexion																		
None	17	0	0	20	0	0	32	0	11									
Soft collar	36	4	13	22	2	8	31	0	12	36	14		34	15		8	5	
Semirigid	38	4	13	19	0	11	28	0	12	38	13		32	15		10	6	
Rigid collar	38	3	15	20	2	8	35	0	14	28	13		32	15		11	8	
Side bend																		
None	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Soft collar	13	5	10	12	2	9				20	20					6	4	
Semirigid	16	6	13	11	2	6				13	18		7	18		15	4	
Rigid collar	15	5	13	5	2	6				16	17		3	17		12	3	
Complete destabilization																		
Flexion																		
None	17	4	13	20	0	0	39	15	6									
Soft collar	30	8	15	24	7	7	36	6	10	26	32		7	20		25	18	
Semirigid	34	4	19	29	2	12	33	5	12	17	33		2	25		22	20	
Rigid collar	37	4	20	35	4	13	33	8	14	25	33		21	20		29	20	
Side bend																		
None	0	0	0				28	26	11									
Soft collar	16	23	2	28	12	30	29	23	9	10	38		29	30		20	27	
Semirigid	4	2	16	27	22	26	15	10	17	15	33		16	30		14	24	
Rigid collar	19	16	23	34	20	26	2	17	19	10	40		14	38		13	29	
Extension																		
None	14	0	0	2	2	1	30	18	2									
Soft collar	35	8	1	27	13	2	3	2	3	37	27		42	32		31	17	
Semirigid	17	11	2	25	13	1	13	22	0	9	23		24	35		14	19	
Rigid collar	23	10	2	30	12	2	30	18	2	23	37		26	32		22	20	
Destabilization of anterior columns only																		
Flexion																		
None	17	0	0	20	0	0												
Soft collar	20	4	2	10	3	4	10	1	1	6	5		8	1		8	5	
Semirigid	28	5	0	18	3	0	16	1	1	12	5		0	1		10	6	
Rigid collar	23	4	3	10	3	3	9	1	1	6	5		4	1		11	8	
Side bend																		
None	0	0	0				14	4	9									
Soft collar	3	1	1	14	1	14	19	2	8	3	11		13	8		9	5	
Semirigid	12	15	7	6	4	14	12	0	4	10	10		15	10		3	4	
Rigid collar	4	2	13	12	0	12	14	2	5	4	11		11	10		6	5	
Extension																		
None	14	0	0	2	2	1	24	11	3									
Soft collar	54	15	8	21	11	2	24	12	2	49	19		43	12		23	4	
Semirigid	44	13	8	19	10	1	17	9	2	27	13		35	10		23	4	
Rigid collar	49	14	6	31	7	2	22	8	4	10	10		39	10		21	4	

A = angulation, °; T = translation, mm; D = distraction, mm. Data are missing where overexposed films could not be accurately measured.

Results

Incomplete posterior destabilization

Data from flexion and side-bending stress challenges in this model are presented in Table 2. Baseline data from cadavers 4, 5 and 6 are unavailable because the x-rays were underpenetrated. Extension stress data are not presented, as the intact anterior tension-band effect of the intact anterior annulus and anterior longitudinal ligament here eliminated extensile hypermobility entirely.

These data (Table 2 and Table 3) record pathologic angulations and displacements well beyond normal.[16] Only measurements from cadaver 6 and flexural data from cadaver 5 approached normal limits. Curiously, when compared with unsupported alignment after destabilization they show *increased* angulation, translation and distraction with all 3 collars in either loading mode, with no statistically significant difference in any of these displacements between types of collar (Table 3). This is consistent with gross observations of the cadaver heads levering over the edges of the collars during these experiments (Fig. 1): after release from the neutral position, the head, neck and collar rolled forward as a unit until the forehead of the cadaver met the tabletop.

Complete destabilization

Data from flexion, side-bending and extension stress-testing in this model are also presented in Table 2. Again, no major limitation to any of the displacements was noted. After release from the neutral position, the movement of the head and neck with the semirigid collar (Fig. 2) was exactly as described for the posterior destabilization model (Fig. 1) until the distal anterior flange of the collar impinged on the manubrium. At this point apparent motion of the neck and collar stopped, but the head continued to roll forward slightly as the chin rolled over the hard proximal flange of the collar, effectively lengthening the neck through a 13-mm translation (see also Table 2).

Available baseline data show a trend toward more movement in the collared specimens than in the unsupported.

There was a trend toward increased flexural translation in prone loading with the soft collar applied, but increased distraction of the index motion segments with more rigid collar support was such that the net malalignment was similar in all cases.

Table 3

Mean translations and flexural angulations in cadavers (*n* = 6), unsupported and in 3 types of cervical collar

Destabilization model	None	Soft	Semirigid	Rigid
Posterior only				
Displacement, mm	0	7	7	12
Angulation, °	23	28	28	27
Complete				
Displacement, mm	6	17	15	20
Angulation, °	25			
Anterior only				
Displacement, mm	0	3	4	4
Angulation, °	19	10	14	11

FIG. 1. Cadaver 4. Posterior-only destabilized model, prone loading, soft collar. See text for descriptions of movement.

FIG. 2. Cadaver 4. Posterior-only destabilized model, prone loading, semirigid collar.

FIG. 3. Cadaver 4. Posterior-only destabilized model, prone loading, hard collar.

With side-bending stress the data showed a trend toward increased angulation with the soft collar (Table 3), but even the more rigid collars often allowed angulation of over 10°, bringing their effectiveness into question.

Extension stressing of this model showed little variance of displacements between orthoses.

Incomplete anterior destabilization (posterior elements sutured)

In this model (Table 2), all flexural stress resulted in major displacements. In side-bending there was again little variance by type of orthosis. In extension the soft collar permitted increased angulation in some specimens, compared with the more rigid collars; but again, the large displacements recorded even with the stiffer devices suggests that they offer minimal protective benefit (Table 3). Observed motion with the hard collar (Fig. 3) was exactly as described with the semirigid collar (Fig. 2).

Discussion

We have studied the net immobilization provided to the geriatric neck in a fresh cadaver model with 3 degrees of cervical subaxial discoligamentous disruption.

Our model recreates an extreme instability situation, with axial spine structure disrupted and supportive effect provided by neither the usually stiffened soft tissues of a preserved cadaver nor the normal muscle tone of a living subject. Our model may also be limited in testing for displacements in the horizontal position under gravity load. This situation was purposefully chosen to mimic as closely as possible the situation of the trauma patient who is unconscious and bedridden or stretcher-bound, not ambulatory or mobile.

Our model may also be flawed in testing the extreme of completely unopposed neck flexion, side-bending and extension stress. These results may also not be generalizable to the necks of young patients, given the advanced age and clinically kyphotic alignment of our specimens.

No effective limitation of any angulation or displacement was found. Flexural stress applied to the posterior-only destabilized model (Table 2), which may represent the most common clinical concern,[1,29,30] caused no major differences in anterior angulation or measured displacements. There were also only minor differences between the soft and more rigid orthoses noted during testing of the next 3 most directly stressing modes (prone flexural stress and decubitus side-bending in the completely destabilized model, and supine extensile stress in cadavers with anterior destabilization only).

Axial translation was recorded frequently, in magnitudes up to 38 mm (Table 2). Gross lengthening of the neck as would correspond to these translations was observed often during the experiments.

Observers noted that after release from the neutrally aligned position, each cadaver head would fall initially as a unit with the neck and collar. The leading distal edge of the collar would quickly meet the upper sternum (prone loading), trapezius region (side bending) or cervicodorsal junction (supine loading), whereupon gross motion of the neck and collar would stop. The proximal leading edge of the collar would impinge upon the chin (flexural loading), jaw (side bending) or occiput (supine loading); the cadaver head would then roll over the edge of the collar to its final displaced position, the neck lengthening slightly as it went.

An unexpected and previously unreported finding was that in most loading modes, angulation and displacement of the unsupported cadaver neck was consistently *less* than with many of the applied orthoses. This counterintuitive observation is consistent with the cadaver neck "levering" over the collar edge, as grossly observed and noted during these experiments. This pattern suggests that the mechanical effects of a cervical orthosis come not simply from restriction of normal neck motion: in necks not constrained by normal ligament tension and muscle tone, the bulk of a cervical orthoses resisting compression may actually increase cervical displacements under load as the mobile head and proximal cervical segments lever or "vault" over the firm edge of the applied brace.

These unexpected observations of increased displacement are reminiscent of the mechanical observations of Foley[31] and DiAngelo[32] and their respective colleagues, who studied the loading of cervical strut grafts with anterior cervical plating in cadavers. Those groups found that cervical flexion compressed uninstrumented strut grafts, as expected, but unloaded them after rigid instrumentation was applied. Their observations of the mechanics are consistent with the cadaver neck "vaulting" over the rigid plates in flexion, much as we have observed the heads of our cadavers levering over the edges of the applied collars.

Our data suggest both that there is little advantage to using "hard" rather than "soft" cervical orthoses to limit mobility of the potentially unstable neck, and that none of the devices studied provide significant mechanical immobilization.

Conclusion

The routine use of a hard cervical collar to protect the neck of an unconscious trauma patient from secondary displacement may not be effective.

Clinicians cannot depend on hard cervical collars to provide definitive support to the neck in cases of possible cervical instability.

For patients in collars who are being treated, there appears to be little benefit from hard versus softer devices.

In cases where tone in cervical soft

tissue is lacking, the cervical orthoses studied may facilitate increased displacement of the unstable neck under load, as compared with the unsupported condition. Appropriate precautions in the care of cervical spine–injured patients are accordingly warranted.

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