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ORIGINAL ARTICLE

A case-control study of cerebellar tonsillar ectopia (Chiari) and head/neck trauma (whiplash)

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Abstract

Primary objective: Chiari malformation is defined as herniation of the cerebellar tonsils through the foramen magnum, also known as cerebellar tonsillar ectopia (CTE). CTE may become symptomatic following whiplash trauma. The purpose of the present study was to assess the frequency of CTE in traumatic vs non-traumatic populations.

Study design: Case-control.

Methods and procedures: Cervical MRI scans for 1200 neck pain patients were reviewed; 600 trauma (cases) and 600 non-trauma (controls). Half of the groups were scanned in a recumbent position and half were scanned in an upright position. Two radiologists interpreted the scans for the level of the cerebellar tonsils.

Main outcomes and results: A total of 1195 of 1200 scans were read. CTE was found in 5.7% and 5.3% in the recumbent and upright non-trauma groups vs 9.8% and 23.3% in the recumbent and upright trauma groups ($p = 0.0001$).

Conclusions: The results described in the present investigation are first to demonstrate a neuroradiographic difference between neck pain patients with and without a recent history of whiplash trauma. The results of prior research on psychosocial causes of chronic pain following whiplash are likely confounded because of a failure to account for a possible neuropathologic basis for the symptoms.

Keywords: *Whiplash trauma, Chiari, cerebellar tonsillar ectopia, upright MRI*

Introduction

Chiari Type I malformation is traditionally defined as caudal herniation of the cerebellar tonsils through the foramen magnum or tonsillar ectopia. The condition may be associated with syringomyelia and osseous abnormalities at the craniovertebral junction, but may occur in the absence of both as well. Chiari Type II, also known as Arnold-Chiari malformation, is differentiated from Chiari I in as much as it is present at birth, nearly always

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associated with myelomeningocele (spina bifida) and includes downward displacement of the medulla, fourth ventricle and vermis of the cerebellum into the cervical spinal canal [1].

Symptoms that are most often associated with Chiari type I malformation are occipital headache, neck pain, upper extremity numbness and paresthesias and weakness [2, 3]. In a few cases there can also be lower extremity weakness and signs of cerebellar dysfunction [4]. The criterion for diagnosis of a Chiari Type I malformation is most frequently given as magnetic resonance imaging (MRI) evidence of low cerebellar tonsils relative to the foramen magnum [5, 6]. The threshold for diagnosis is variable; most authors have suggested that to be considered pathologic the cerebellar tonsils must be 5 mm or more below an imaginary line that runs from the basion (the most anterior point of the foramen magnum) to the opisthion (the posterior point of the foramen magnum) [7]. Other authors have suggested that the range of normal tonsil position ends at 2 mm below the basion-opisthion line (B-OL) [8]. The term tonsillar 'ectopia' is used to characterize any condition in which the cerebellar tonsils are found to be below the B-OL, regardless of symptom presence [8].

Several authors have suggested that previously quiescent Chiari Type I malformations can become symptomatic as a result of exposure to traumatic injury. In their seminal paper describing 364 cases of symptomatic Chiari Type I cases, Milhorat et al. [2] noted that 24% of their subjects described a traumatic event that precipitated their symptoms. Wan et al. [9] described a symptomatic 'conversion' of previously asymptomatic Chiari Type I following minor head and neck trauma. Other authors have described the discovery of symptomatic Chiari Type I following motor vehicle crashes and what is typically described as 'whiplash' trauma [10, 11], in which the injury mechanism is a result of inertial loading of the spine and skull [12].

There is no clear consensus regarding how trauma may play a role in the activation of symptoms that are attributed to a Chiari Type I or a lesser degree of cerebellar tonsillar ectopia (CTE). Are the symptoms coincidental to the trauma? Is the condition symptomatically 'awakened' by the trauma? Could the downward displacement of the tonsils be caused by the trauma? This last question is important, since quite often the presence of tonsillar ectopia is not discovered until imaging is performed following head or neck trauma and acquired tonsillar herniation is radiographically indistinguishable from a pre-existing CTE [3].

In order to address some of these questions, the present study describes an evaluation of the prevalence of CTE in two sub-populations (trauma and non-trauma) of neck pain patients referred for MR imaging of the cervical spine using a case-control study design. Further, the effect of gravity dependence on tonsil level and its interaction with a history of trauma was assessed by performing the MRI scan in a traditional horizontal position in a recumbent scanner or in a vertical position in an upright scanner.

Methods

MR imaging films of the cervical spine and base of the skull from 1200 consecutive neck pain patients 15 years and older presenting to four different outpatient radiology centres over a 3-year period were acquired and reviewed. Half of the scans (600) were from patients with neck pain resulting from a motor vehicle crash (cases) and half were from patients without a recent history of trauma (controls). Further, half of the cases and half of the controls were scanned in a 0.6 T Fonar upright open architecture MRI scanner (Fonar Corporation, Melville, NY) and the remaining half were obtained from a facility with a 0.7 T recumbent open architecture Hitachi Altaire MRI scanner (Hitachi Medical Systems, Tokyo, Japan). The resulting four study groups had 300 scans each in them—Recumbent Non-trauma (RNT), Upright Non-trauma (UNT), Recumbent Trauma (RT), and Upright Trauma (UT). Subject anonymity was maintained by the removal of all personal identifiers from the scans and patient histories and IRB approval was sought and received from the Spinal Injury Foundation (Westminster, CO).

Traditional MR imaging sequences were used and included parasagittal to midsagittal slices. Sagittal sequences selected for measurement were those that showed the cerebellar tonsils at their lowest point relative to the B-OL. Sequences used on the upright scanner were T2 fast spin-echo TR 1011, TE 160 with slice thickness of 3.5 mm, interval 4; and T1 fast spin-echo TR 366, TE 17, with slice thickness of 3.5 mm, interval 4. Sequences used on the recumbent scanner were T2 fast spin-echo sagittal TR 3500, TE 120, with a slice thickness of 3 mm, interval 4; and T1 SE sagittal TR 400, TE 16, with a slice thickness of 3 mm and interval 4.

The films were interpreted by two board certified radiologists (authors DH and FS) who were blinded with regard to the injury or scan position status. The metric of interest was the level of the cerebellar tonsils relative to the level of the foramen magnum, defined by a line drawn from the basion to the opisthion, the basion-opisthion line or B-OL (Figure 1).

Figure 1. The Basion-Opisthion Line (double arrow).

The scans were classified by the level of the lowest point of the cerebellar tonsils relative to the B-OL. The level of agreement between the two radiologists was assessed, and in cases where there was disagreement the more conservative (more cephalad) assessment of tonsil station was used for the statistical tests.

The results were described in terms of average tonsil level as well as the relative proportion of scans with tonsils 1 mm or more below the level of the foramen magnum for each group and by gender. Three-way analysis of variance (ANOVA) with a Tukey pairwise comparison was used to evaluate for significant differences in average tonsil level among the sub-groups (cases to controls, upright to recumbent, male-to-female) and Chi-square goodness of fit test was used for evaluation of the proportional differences between the groups. Comparisons were statistically significant when $p \leq 0.05$. A Kappa statistic was used to assess the level of agreement between the two radiologists (Analyse-It, Leeds, UK).

Results

Of the 1200 scans, five were considered uninterpretable for tonsil station by one of the radiologists and all five of these studies were in the recumbent trauma group. Amongst the remaining 1195 subjects the average age was 41.5 and 39.7 years in the cases and 57.4 and 54.0 years in the controls (recumbent and upright, respectively). A majority of subjects were female in all groups (Table I).

There was excellent agreement between the two readers regarding tonsil station (kappa range 0.85–0.95). Both injury status and scan type (recumbent vs upright) were associated with significant differences in the average level of the tonsils ($p \leq 0.0001$). The highest (most cephalad) mean tonsil level was found in the recumbent non-trauma group at 2.2 mm above the B-OL, followed by the non-trauma upright group at 1.7 mm. The recumbent trauma group average tonsil level was somewhat lower at 1.3 mm above the B-OL and the lowest station by far was observed in the upright trauma group at 0.1 mm (or nearly even with the B-O line). The pairwise comparison indicated that the trauma cases had significantly lower average tonsil levels than controls for both upright and recumbent scan groups. There were also significant differences observed in tonsil level between the male and female groups among the recumbent trauma and upright non-trauma groups, with the average level in all of the female groups lower than those of the male groups ($p \leq 0.0001$) (Table II).

Tonsillar herniation of 5 mm and more was rare in all of the groups; there were a total of only six cases in all groups, with three in the trauma groups (two upright and one recumbent) and three in the non-trauma groups (one upright and two recumbent). In contrast, there were quite substantial differences between the groups in the frequency of scans with tonsils at 1 mm or more below the B-OL; in the two non-trauma groups the tonsils were below the B-OL in 5.7% and 5.3% of cases in the recumbent and upright groups, respectively, whereas in the trauma groups 9.3% and 23.3% of cases in the recumbent and upright groups were 1 mm or more below the B-OL ($\chi^2 = 0.0001$) (Table II). Similar differences were observed when the groups were stratified by gender, with a significantly larger effect seen among the females ($\chi^2 = 0.0001$). An exemplar of a case with CTE observed in a vertically scanned trauma group patient is depicted in Figure 2.

Discussion

This study reports that patients with a history of motor vehicle crash-associated neck pain have a substantially higher frequency of cerebellar tonsillar ectopia of 1 mm or more than non-traumatic subjects; ~4-times greater when evaluated with an upright MRI scanner. These data represent the first large series of patients scanned in both upright and recumbent MR scanners with the intent of evaluating CTE frequency.

Table I. Age (mean, SD), gender (F/M%).

	Recumbent non-trauma	Upright non-trauma	Recumbent trauma	Upright trauma
Number of subjects	300	300	295	300
Age in years	57.4, 14.47	54.0, 17.74	41.5, 12.90	39.7, 14.37
Gender	60.3/39.7	57.3/42.7	64.8/35.2	62.3/37.7

Table II. Mean tonsil level (mm above B-OL), 95% confidence interval (mm above B-OL), percentage of cases ≥ 1 mm below B-OL.

	All			Female			Male		
	M	95% CI	% CTE	*M*	95% CI	% CTE	*M*	95% CI	% CTE
Recumbent non-trauma	2.2	2.0–2.4	5.7	2.1	1.8–2.4	7.2	2.3	2.0–2.7	5.0
Upright non-trauma	1.7	1.5–1.9	5.3	1.4	1.2–1.7	7.5	2.2	1.9–2.5	2.4
Recumbent trauma	1.3	1.1–1.5	9.3	1.0	0.7–1.3	11.4	1.8	1.4–2.2	6.7
Upright trauma	0.1	−0.1–0.3	23.3	0.0	−0.2–0.3	24.6	0.4	0.0–0.8	19.5

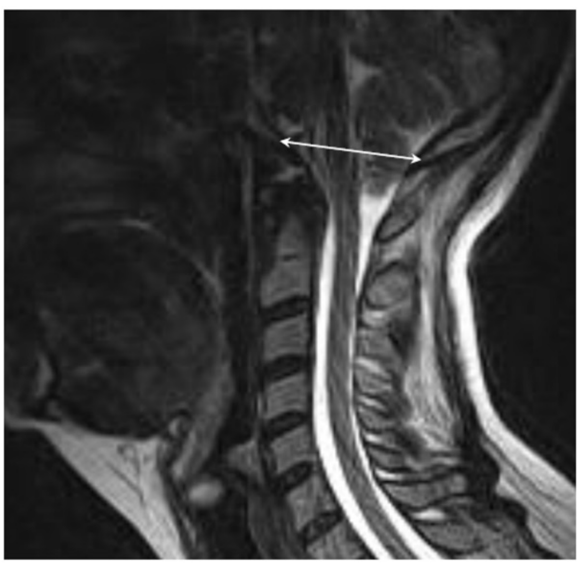

Figure 2. Exemplar of Chiari observed in a subject from the upright trauma group. The double arrow indicates the BO-L.

The mean level of the tonsils in the non-trauma groups was relatively close and the frequency of CTE was also nearly the same. This was not the case with the trauma groups; the recumbent mean tonsil level was substantially more cephalad than the upright. Notably, CTE was found 2.5-times more often in the upright trauma vs the recumbent trauma group and ~4-times more often than in either of the non-trauma groups. Unless the difference between trauma and non-trauma cases was a result of unforeseen variability, it is reasonable to conclude that these results reflect a degree of gravity dependent instability in the trauma group that was not observed in the non-trauma group.

It is probable that the differences observed between the study groups were due to the independent variables of interest (scan type and injury status) rather than some unforeseen bias between the groups. One possible source of bias is the fact that the scans were acquired at four different outpatient imaging centres (two upright and two recumbent), raising the possibility of differing referral criteria. A comparison of the demographics of the patients indicates that the recumbent scan populations were quite similar in age and gender mix to the upright scan populations, once trauma status was taken into account and, thus, the type of facility (upright vs recumbent) did not appear to influence the patient type seen at the facility. The trauma patients were substantially younger than the non-trauma patients, but this was expected as the trauma cases were representative of the mean age of the general population that travels in a motor vehicle, whereas the non-trauma cases were more likely to have neck symptoms associated with age-related degenerative joint and disc disease of the spine [13].

It has been suggested that, relative to a scan performed in a recumbent MR scanner, a scan performed in an upright scanner may demonstrate increased caudal tonsillar ectopia [14]. Mechanically this makes sense; in an upright position the brain will tend to sit lower in the skull than when in a supine position because of a combination of gravitational forces and the configuration of the occiput. When vertical the base of the brain and the spinal cord tend to act as 'cork stopper' in the foramen magnum to the extent allowed by the supporting tissues, and when horizontal the occipital lobe and cerebellum tend to slide in a cephalad direction along the curvature of the posterior skull interior. Ideally, all of the patients would have been scanned first in the recumbent position and then in an upright position, in order to assess tonsillar shift with position change.

These findings beg the question of whether a condition of a previously unknown CTE has been symptomatically awakened by the motor vehicle crash trauma or if the CTE was caused by the trauma. There is some evidence in favour of the latter; the fact that there was a substantial difference observed in the frequency of CTE in the upright vs the recumbent trauma groups that was not present in the non-trauma groups suggests instability of the brain in the trauma group that is gravity dependent. It is well established that Chiari can be acquired; lumbar shunting performed to reduce CSF in cases of hydrocephalus can allow the brain to drop in the skull to the point that the cerebellar tonsils herniate through the foramen magnum. This phenomenon is due to the fact that the flotation level of the brain is dependent on the amount of CSF within the dural covering of the spine and brain [15, 16]. Hypothetically, it then follows that if a dural leak could result from crash trauma then a CSF leak and lowered pressure could explain the findings of lower tonsils in the upright trauma group vs the recumbent group.

There is clinical evidence that dural leaks are associated with whiplash trauma and chronic symptoms; using radioisotope cisternography, Ishikawa et al. [17] described the identification of CSF leaks, primarily in the lumbar spine at the dural sleeves, in 37 of 66 (56%) chronic whiplash patients with headache, memory loss, dizziness and neck pain, *inter alia*. The authors described substantial improvement in chronic symptoms in 32 of the 36 (88%) patients who agreed to epidural blood patch (EBP) therapy. Huntoon and Watson [18] presented a case study in which a 60 year-old woman was exposed to a whiplash trauma and complained of subsequent headache and upper cervical pain. Subsequent MRI examination revealed CTE and finding suggestive of extradural CSF, indicative of a non-specific dural leak. The patient responded positively to EBP therapy.

Although a possible mechanism of dural trauma associated with whiplash trauma is only hypothetical, biomechanical study of a porcine spine model demonstrates substantial pressure changes in the CSF during simulated whiplash trauma; first the pressure drops by ~75 mm Hg and then it increases by more than 150 mm Hg over a period of ~100 ms [19]. Whether this is a sufficient pressure gradient change to cause dural injury in some cases is unknown.

The identification of a here-to-fore unrecognized condition or possible injury to the central nervous system that may be causally associated with motor vehicle crash trauma raises potential concerns regarding the conclusions of prior authors who have studied whiplash injuries as a primarily non-pathologic chronic pain condition. A number of recent papers have evaluated the relationship between psychosocial factors such as litigation status, depression and coping strategies on symptoms associated with whiplash-related neck pain, concluding that all are important and predictive factors in injury outcome [20–22]. These and other prior research efforts have been based on the assumption that there is no definable pathology associated with the chronic pain complaints among the injured subjects. Although this study did not evaluate the relationship between various symptom patterns and the presence or absence of CTE in the 595 whiplash-injured patients, the fact remains that neuroradiographic abnormality was found in approximately one-in-four upright trauma cases in the present study. Thus, while it cannot be concluded that a patient with CTE is more likely to be depressed, have difficulty coping and seek compensation for his injury than one without CTE, it cannot be denied that the condition may have served as a hidden source of confounding in the aforementioned studies and others with similar designs and intent, calling into question the validity of the conclusions of the authors.

Irrespective of whether the radiographic findings of CTE observed in the trauma groups resulted from the crash trauma or was pre-existing, the current study indicates that cerebellar tonsillar ectopia is substantially more prevalent in whiplash-injured neck pain patients than in neck pain patients with no recent history of trauma. Of incidental note is the fact that the proportion of upright scans with CTE in the present study is approximately the same as the proportion of whiplash-injured patients who go on to report chronic pain symptoms from their injury reported by some authors [23].

A limitation of the present study is the lack of detail in the differentiation between the traumatic and non-traumatic subjects regarding a recent history of whiplash trauma. Further information regarding the prevalence of a remote history of trauma among the non-traumatic subjects would have been informative for further comparison between the groups. Several authors have reported that nearly half of the population with chronic neck pain attribute the onset of their pain to a whiplash trauma-associated injury [24, 25]. Accordingly, it is reasonable to assume that some proportion of the subjects in the non-trauma groups did have a prior history of whiplash injury. As a source of error, this assumption would have minimized rather than increased the differences between the groups, resulting in the probable under-estimation of the ratios of CTE reported herein.

A second limitation is the lack of detailed information regarding the symptoms of the study subjects. Previous authors have described a myriad of neurological complaints associated with a diagnosis of a symptomatic Chiari malformation following head and neck trauma [26, 27]; however, virtually all patients complain of headache and many complain of neck pain, the two symptoms most commonly associated with whiplash injury [28]. The difficulty of evaluating the causal relationship between whiplash injury-related symptoms and the finding of CTE is further complicated by the fact that a causal association has been described in the literature between whiplash injury and fibromyalgia syndrome (FMS) [29, 30]. Further, Heffez et al. [31] have described a higher than expected frequency of Chiari I malformations among a group of 270 patients with FMS (20%), with the lead author noting that more than 70% were observed to have some degree of CTE (personal communication with D. Heffez, 15 October 2008). Thus, CTE has been found to be associated with both a history of whiplash trauma and FMS. Although there are more questions than answers generated by this observation, an appealing hypothesis is one that links FMS to whiplash injury via an acquired CTE resulting from the whiplash trauma, possibly secondary to the type of dural leak described by Ishikawa et al. [17].

Future study that would advance the understanding of the relationship between CTE and whiplash trauma should include a detailed neurologic evaluation and elicited pre- and post-injury history of Chiari-unique headache symptoms (e.g. cough exacerbation) as well as recumbent and upright MRI assessment of CTE status.

Conclusions

The results reported herein are the first to demonstrate a substantial neuroradiographic difference between neck pain patients with and without a recent history of motor vehicle crash trauma. Upright position MR imaging appears to increase the sensitivity to CTE over recumbent MR imaging by 2.5-times. Future research should include efforts to confirm these results as well as biomechanical research into whether injury-related mechanisms could result in dural injury and subsequent leaking. A prospective long-term follow-up of whiplash injury cases by cerebellar tonsillar ectopia status would provide useful information in understanding post-traumatic neck pain and related syndromes.

Clinicians may want to consider evaluating patients for CTE (i.e. upright MRI of the neck and head) when there is a history of whiplash trauma and persisting suboccipital headache in combination with headache worsened by cough or bilateral sensory or motor deficits in the upper extremities. In CTE patients with headache that is relieved when supine it also may be appropriate to consider radionuclide cisternography to evaluate for the presence of a dural leak.

***Declaration of interest*:** Dr Harshfield has a financial interest in an imaging centre with an upright MRI. The authors report no further conflicts of interest. The authors alone are responsible for the content and writing of the paper.

References

1. Stevenson KL. Chiari Type II malformation: Past, present, and future. Neurosurgery Focus 2004;16:5.
2. Milhorat TH, Chou MW, Trinidad EM, Kula RW, Mandell M, Wolpert C, Speer MC. Chiari 1 malformation redefined: Clinical and radiographic findings for 364 symptomatic patients. Neurosurgery 1999;44:1005–1017.
3. Payner TD, Prenger E, Berger TS, Crone KR. Acquired Chiari malformations: Incidence, diagnosis, and management. Neurosurgery 1994;34:429–434.
4. Wolf DA, Veasey DA, Wilson SK, Adame J, Korndorffer WE. Death following minor head trauma in two adult individuals with the Chiari I deformity. Journal of Forensic Science 1998;43:1241–1243.
5. Ball WS, Krone KR. Chiari malformation from Dr. Chiari to MR imaging. Radiology 1995;195:602–604.
6. Elster AD, Chen MY. Chiari 1 malformations: Clinical and radiological reappraisal. Radiology 1992;183:347–353.
7. Meadows J, Kraut M, Guarnieri M, Haroun RI, Carson BS. Asymptomatic Chiari type I malformations identified on magnetic resonance imaging. Journal of Neurosurgery 2000;92:920–926.
8. Barkovich AJ, Wippold FJ, Sherman JL, Citrin CM. Significance of cerebellar tonsillar position on MR. AJNR: American Journal of Neuroradiology 1986;7:795–799.
9. Wan MJ, Nomura H, Tator CH. Conversion to symptomatic Chiari I malformation after minor head or neck trauma. Neurosurgery 2008;63:748–753.
10. Patticò F, Perfetti P, Gabrieli A, Longo D, Caroselli C, Ricci G. Chiari I malformation with syrinx: An unexpected diagnosis in the emergency department. European Journal of Emergergency Medicine 2008;15:342–343.
11. Bunc G, Vorsic M. Presentation of a previously asymptomatic Chiari I malformation by a flexion injury to the neck. Journal of Neurotrauma 2001;18:645–648.
12. Stemper BD, Yoganandan N, Gennarelli TA, Pintar FA. Localized cervical facet joint kinematics under physiological and whiplash loading. Journal of Neurosurgery Spine 2005;3: 471–476.
13. Matsumoto M, Fujimura Y, Suzuki N, Nishi Y, Nakamura M, Yabe Y, Shiga H. MRI of cervical intervertebral discs in asymptomatic subjects. British Journal of Bone Joint Surgery 1998;80:19–24.

14. Elsig JP, Kaech DL. Imaging-based planning for spine surgery. Minimally Invasive Therapy Allied Technology 2006;15:260–266.
15. Caldarelli M, Novegno F, Di Rocco C. A late complication of CSF shunting: Acquired Chiari I malformation. Childs Nervous System 2009;25:443–452.
16. Chumas PD, Armstrong DC, Drake JM, Kulkarni AV, Hoffman HJ, Humphreys RP, Rutka JT, Hendrick EB. Tonsillar herniation: The rule rather than the exception after lumboperitoneal shunting in the pediatric population. Journal of Neurosurgery 1993;78:568–573.
17. Ishikawa S, Yokoyama M, Mizobuchi S, Hashimoto H, Moriyama E, Morita K. Epidural blood patch therapy for chronic whiplash-associated disorder. Anesthesia and Analgesia 2007;105:809–814.
18. Huntoon MA, Watson JC. Intracranial hypotension following motor vehicle accident: An overlooked cause of post-traumatic head and neck pain? Pain Practice 2007;7: 47–52.
19. Siegmund GP, Winkelstein BA, Ivancic PC, Svensson MY, Vasavada A. The anatomy and biomechanics of acute and chronic whiplash injury. Traffic Injury Prevention 2009;10: 101–112.
20. Cassidy JD, Carroll LJ, Côté P, Lemstra M, Berglund A, Nygren A. Effect of eliminating compensation for pain and suffering on the outcome of insurance claims for whiplash injury. New England Journal of Medicine 2000;342: 1179–1186.
21. Côté P, Hogg-Johnson S, Cassidy JD, Carroll L, Frank JW. The association between neck pain intensity, physical functioning, depressive symptomatology and time-to-claim-closure after whiplash. Journal of Clinical Epidemiol 2001;54:275–286.
22. Carroll LJ, Cassidy JD, Côté P. The role of pain coping strategies in prognosis after whiplash injury: Passive coping predicts slowed recovery. Pain 2006;124:18–26.
23. Freeman MD, Croft AC, Rossignol AM, Weaver DS, Reiser M. A review and methodologic critique of the literature refuting whiplash syndrome. Spine 1999;24:86–98.
24. Freeman MD, Croft AC, Rossignol AC, Centeno CJ, Elkins W. Chronic neck pain and whiplash: A case/control study of the relationship between acute whiplash injuries and chronic neck pain. Pain Research Management 2006;11: 79–83.
25. Côté P, Cassidy JD, Carroll L. Is a lifetime history of neck injury in a traffic collision associated with prevalent neck pain, headache and depressive symptomatology? Accident Analysis and Prevention 2000;32:151–159.
26. Murano T, Rella J. Incidental finding of Chiari I malformation with progression of symptoms after head trauma: Case report. Journal of Emergency Medicine 2006;30: 295–298.
27. Uzoigwe CE, Shabani F, Chami G, El-Tayeb M. Simple whiplash? British Journal of Bone Joint Surgery 2009;91: 1103–1104.
28. Obermann M, Nebel K, Riegel A, Thiemann D, Yoon MS, Keidel M, Stude P, Diener HC, Katsarava Z. Incidence and predictors of chronic headache attributed to whiplash injury. Cephalalgia 2009; [Epub ahead of print]. PMID: 19673910.
29. Buskila D, Neumann L, Vaisberg G, Alkalaly D, Wolfe F. Increased rates of fibromyalgia following cervical spine injury. A controlled study of 161 cases of traumatic injury. Arthritis and Rheumatism 1997;40:446–452.
30. McLean SA, William DA, Clauw DJ. Fibromyalgia after motor vehicle collision: Evidence and implications. Traffic Injury Prevention 2005;6:97–104.
31. Heffez DS, Ross RE, Shade-Zeldow Y, Kostas K, Shah S, Gottschalk R, Elias DA, Shepard A, Leurgans SE, Moore CG. Clinical evidence for cervical myelopathy due to Chiari malformation and spinal stenosis in a non-randomized group of patients with the diagnosis of fibromyalgia. European Spine Journal 2004;13:516–523.