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...
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).
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.
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 neurologically evaluated 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


Introduction

Atlantoaxial instability (AAI) occurs as a result of trauma, congenital conditions such as os odontoideum, neoplasm, infection and degenerative connective tissue disorders such as rheumatoid arthritis, genetic conditions such as HOX-D3 and Down syndrome, and heritable connective tissue disorders, emblematic of which are the Ehlers Danlos syndromes (EDS). Prototypical of disorders in which AAI is diagnosed, is rheumatoid arthritis (RA). Prior to the development of effective disease-modifying pharmacotherapies, 88% of RA patients exhibited radiographic evidence of C1-C2 involvement, in whom 49% were symptomatic and 20% myelopathic; ultimately, 10% may have suffered atlantoaxial dislocation and death [1-3].

In their report on pediatric patients undergoing C1-C2 transarticular screw fixation Gluf and Brockmeyer noted approximately one third of the cases of AAI resulted from trauma, one third from os odontoideum, and one third from congenital conditions such as Down syndrome, Stiil disease, dwarfism, Morquio syndrome, Klippel-Feil and others. Three patients were thought to have chronic instability, most likely to have resulted from ligamentous laxity, possibly EDS [4,5].

The diagnosis of AAI is not difficult in the presence of an abnormal ADI (Figure 1), but may be elusive in those cases where the transverse ligament is intact, and where there is incompetence of one or both the alar ligaments. In these cases, the diagnosis may require dynamic imaging and concordant clinical findings.

Etiology of Atlantoaxial Instability

Traumatic flexion of the neck may result in injury to the transverse odontoid ligaments and alar ligaments. An atlanto-dental interval (ADI) over 3 mm suggests possible instability in adults; an ADI exceeding 5 mm suggests instability in children. An ADI of 7 mm suggests rupture or incompetence of the transverse ligament, and/or of the cruciate ligament, and an ADI of 10 mm suggests loss or incompetence of the alar ligaments as well [6]. However, if the transverse ligament is intact, the ADI is normal despite the presence of alar ligament incompetence.

A proclivity to ligamentous incompetence renders the atlantoaxial joint at higher risk for instability. The atlantoaxial junction (AAJ) is the most mobile joint of the body. Held together by ligaments that allow a great degree of freedom of rotation, the AAJ is responsible for 50% of all neck rotation, 5° of lateral tilt, and 10° to 20° of flexion/extension [7]. It is not surprising therefore, that connective tissue disorders, such as Down syndrome and EDS, are more frequently visited by AAI. Motor delay [8,9], headache associated with “connective tissue pathological relaxation” and quadraparesis are attributed to ligamentous laxity and instability at the atlanto-occipital and atlantoaxial joints [10,11]. While the epidemiology of AAI in EDS-hypermobile type is unknown, AAI was seen in two thirds of patients with EDS-Vascular type [11]. A high risk of AAI is apparent in other connective tissue disorders, including 11% of Down syndrome patients [12].

The AAJ mechanical properties are determined by ligamentous structures [13,14], most prominent of which are the transverse and alar ligaments [15]. The alar ligaments limit axial rotation and lateral bending to the contralateral side, are often injured in motor vehicle collisions, and could be implicated in whiplash-associated disorders [15]. Failure of the alar ligament allows a 30% increased rotation to the opposite side [16]. The atlantoaxial joint is ill-equipped to handle the required multi-axial movements in the presence of ligamentous laxity or disruption [17]. Weakness of the muscles and ligaments, hormonal changes, infection, immunological problems, and congenital dysmorphism may contribute to the overall mechanical dysfunction at the C1-C2 motion segment.

Hypermobility of the AAJ is common in children, and up to 45° of rotation may be observed in each direction. However, in the adult there is substantially less than 40° of rotation [17-20]; at 35° of rotation of C1 upon C2 there is stretching and kinking of the contralateral vertebral artery [20]; at 45°, both vertebral arteries become occluded [21].

Diagnostic Findings

Diagnosis of AAI is based upon careful history, a detailed neurological exam and imaging of the upper cervical spine. The most common clinical features are neck pain and suboccipital headache, with the caveat that headache is present in 50% of patients with EDS [22], and that moderate pain is a common occurrence for most EDS patients. There may be symptoms referable to the vertebral artery blood flow, including visual changes, as well as headache associated with the vertebral artery itself. Syncope and presyncope events are frequent. Other symptoms include dizziness, nausea, sometimes facial pain, dysphagia, choking, and respiratory issues. There is usually improvement with a neck brace. Examination often demonstrates tenderness over C1-C2, altered mechanics of neck rotation, hyperreflexia, dysdiadochokinesia, hypoaesthesia to pinprick. Weakness is not a constant feature of AAI [4,23-27].

Radiological features may show atlanto-dental interval (ADI) >2.5 mm in an adult, or 5 mm in a child, on lateral flexion x-rays (Figure 1) or rotation of C1 upon C2 >41° [4,28] (Figure 2). Excessive rotation occurs opposite to the side of an incompetent alar ligament. Alar ligament incompetence is the most frequent cause of AAI in the population of patients with hypermobility connective tissue disorders [4]. Thus diagnosis of AAI in EDS, or related connective tissue disorders, is best made with supine computed tomography (CT), from occiput to C2, with full neck rotation (90° if possible) to left and to right. (Figure 2) The difficulty of recognizing rotary instability on standard x-ray, CT and MRI images has resulted in failure to diagnose [29].

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In the hypermobility disorders, there may be abnormal facet overlap on full neck rotation <20% [30,31] (Figure 3); lateral translation of the facet joints: translation in aggregate >7 mm on coronal imaging as seen on open mouth odontoid views. Open mouth odontoid views are very effective in identifying AAI [32] (Figure 4).

Dvorak showed in cadavers that the mean axial rotation between the axis and the second cervical vertebra was 31.1°, increasing to 35° after contralateral rupture of the alar ligament; CT imaging thus demonstrated increased angular rotation of 4° to the side opposite the alar ligament injury [16].

The diagnosis of AAI can sometimes be seen on three dimensional CT, where there may be a clear demonstration of subluxation [31]. Increased ligament signal intensity on high-resolution proton density-weighted MRI may be seen, with the caveats that alar ligaments of asymptomatic patients may show high signal intensity, and that there is variable inter-examiner reliability of MRI evaluation [33]. Other radiological indications of AAI include compromise of the vertebral arteries based upon abnormal mechanics at the C1-C2 junction; anomalous joints; retro-odontoid pannus [23,27,34] (Table 1).

**Criteria for Surgery**

The decision to proceed to surgery rests upon the presence of severe neck or suboccipital pain, the presence of cervical medullary syndrome or syncopal (or pre-syncopal) episodes, demonstrable neurological findings and radiological evidence of instability or compression of the neuraxis.

**Treatment**

For milder form of instability, the patient should be considered for treatment with neck brace, physical therapy and avoidance of activities that provoke exacerbation of the AAI symptoms. If the non-operative treatment fails, fusion-stabilization at C1-C2 is required. Failure of any of the components of the atlantoaxial ligament complex requires dorsal surgical fusion [35]. This is most often accomplished with posterior screw constructs, transarticular screw fixation [24], or C1-C2 lateral mass/pedicle screws and interposed graft [4,25,26] (Figure 5). Aberrant vertebral artery anatomy may preclude the desired screw placement in 18% to 23% of patients [36,37], and the surgery may be complicated in EDS by small bone architecture.
ADI (Atlanto-dental interval) >3 mm in an adult, or 5 mm in a child, on lateral flexion x-rays.

Lateral translation of the facet joints: translation in aggregate >7 mm on coronal imaging as seen on open mouth odontoid views. Open mouth odontoid views are very effective in identifying AAI [32].

Rotation of C1 upon C2, >41° [4,28] (Figure 1).

Facet overlap on full neck rotation <20% [30,31] (Figure 2).

Greater than 8° difference between the left and right axial rotation, on axial CT with full neck rotation [37].

Three-dimensional CT demonstrating subluxation (Figure 3).

Increased ligament signal intensity on high-resolution proton density-weighted MRI, with the caveats that alar ligaments of asymptomatic patients may show high signal intensity and that there is variable inter-examiner reliability of MRI evaluation [33].

Compromise of the vertebral arteries based upon abnormal mechanics at the C1-C2 junction.

Anomalous joints.

Retro-odontoid pannus [23,27,34].

Occiput to C1/C2 fusion should be considered in the presence of craniovertebral instability, basilar invagination or complex Chiari malformation.

**Conclusion**

AAI results from trauma, congenital conditions, neoplasm, infection, degenerative connective tissue disorders, genetic conditions such as the HOX-D3 or Down syndrome, and heritable connective tissue disorders, emblematic of which are the Ehlers Danlos syndromes. AAI in the hypermobility disorders usually requires dynamic imaging to demonstrate ligamentous incompetence. Radiological findings which are concordant with clinical findings should prompt consideration of surgery.

**References**


Upright Magnetic Resonance Imaging of the Craniocervical Junction

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Magnetic Resonance Imaging (MRI) is conventionally performed in the supine position, where no information about the effect of gravity on the patient in the upright position is possible. Humans spend the larger part of each day in the upright position, where most of their musculoskeletal ailments are experienced. This is especially so along the spinal axis and in the weight-bearing joints. With the capability of scanning patients in the upright position, so has come the ability to use MRI to examine the brain, spine, and major joints in the upright position under the effects of gravity. It is not only the alterations in the biomechanics of the body that can be observed, it is also alterations in blood flow, venous drainage and cerebral spinal fluid flow that are now amenable to the study under the effects of gravity.

This is especially so at the cranio-cervical junction and in the cervical spine, where the weight of the head on the neck can result in significant alteration in the MRI appearance between the supine and upright positions. An adult human head constitutes around 8% of the whole body mass and weighs somewhere between 4.5 and 5 kg (9–11 lb) [1]. This weight exerts significant pressure on the cranio-cervical junction and the cervical spine. The value of being able to image in the upright position is well demonstrated in the case of a 50-year-old woman who had been suffering for many years from neck pain. A prior supine MRI examination had shown a mild degenerative intervertebral disc bulge at the C5–C6 level with a moderate segmental kyphosis (Fig. 1). Despite repeated attempts with conservative treatment, the patient’s symptoms worsened and were marked by the onset of transient paraesthesia, transient loss of muscle tone in the legs and drop attacks, which could not be explained by the disc bulge seen in the MRI examination. An examination in the upright position shows the full extent of the posterior disc bulge at the C5–C6 level, with an increase in the segmental kyphosis. More importantly it shows the presence of downward herniation of the cerebellar tonsils with compression of the brainstem, the full extent of which is not appreciated in the supine examination (Fig. 2).

![Fig. 1. Supine MRI examination.](image1)

![Fig. 2. Upright MRI examination.](image2)
Downward herniation of the cerebellar tonsils, tonsillar ectopia, is graded as a Chiari type 1, traditionally defined as caudal herniation of the cerebellar tonsils through the foramen magnum. The criterion for diagnosis of a Chiari Type I malformation is most frequently given as MR evidence of cerebellar tonsils extending greater than 3–5 mm below the foramen magnum. [2] Chiari type II also known as Arnold-Chiari malformation, is differentiated from a Chiari type I in as much as it is present at birth and nearly always associated with myelomeningocele and includes downward displacement of the medulla, fourth ventricle and cerebellum into the cervical spinal canal [3].

The threshold for diagnosis is variable, some authors have suggested that to be considered pathologic the cerebellar tonsils must be 3–5 mm or more below an imaginary line that runs from the basion, or the most anterior point of the foramen magnum, to the opisthion, or the posterior point of the foramen magnum, the basion-opisthion line or McRae’s line (Figure 3) [4]. Others have suggested that the range of normal tonsil position ends at 2 mm below the basion-opisthion line [5].

While this classification is still widely used today, research shows that the degree of tonsillar herniation is not related to severity of symptoms. In fact, some people with significant tonsillar herniation, greater than 3 mm, have no symptoms. In a study of over 12,000 MRI scans it was found that over 30% of the people who had herniation greater than 5 mm were symptom free [6].

On the other hand, some people exhibit classic Chiari-type symptoms where the tonsils lie at the level of the foramen magnum or just below. This observation is referred to as Chiari 0 malformation. This is a controversial topic especially since the term Chiari 0 was first used by a group of researchers led by Dr. Jerry Oakes, where they identified five patients with syringomyelia and no evidence of tonsillar herniation (i.e. no Chiari I malformation) [7]. Today, by common usage, the term is applied to low lying cerebellar tonsils, at or below the foramen magnum, regardless of the presence or absence of syringomyelia.

In the study of patients following hyperflexion/extension injury (whiplash injury) the question of symptomatic activation of previously quiescent Chiari Type I malformations as a result of exposure to traumatic injury has been reported (8–11). It is not clear how trauma plays a role in the activation of symptoms attributed to a Chiari Type I malformation. Are the symptoms merely coincidental to the trauma or is the condition symptomatically ‘awakened’ by the trauma?

Could the Chiari Appearances Be Caused by the Trauma?

This last question is important, since quite often the presence of tonsillar ectopia is not discovered until after trauma, and acquired tonsillar herniation is radiologically indistinguishable from a pre-
existing Chiari Type I [12]. In an effort to assess the incidence of Chiari 0 in patients following whiplash injury and also to assess if this observation is better made with the patient scanned upright rather than recumbent (supine), the MRI studies of the cervical spine and base of the skull from 1,200 consecutive neck pain patients 18 years and older presenting to 4 different outpatient radiology centres over a 3-year period were reviewed. Half of the scans (600) were acquired from a facility with a 0.6-tesla upright open architecture MRI scanner. The other half (600) were obtained from a facility with a 0.7-tesla conventional recumbent open MRI scanner. Half were from patients with neck pain following a road traffic accident. Half were from patients with no recent history of trauma.

The resulting 4 groups comprise 300 scans each; recumbent nontrauma, upright nontrauma, recumbent trauma, and upright trauma. The images were interpreted by two radiologists, blinded with regard to the clinical history and scanner type. The scans were categorized by the level of the lowest point of the cerebellar tonsils relative to the basion-opisthion line. (Table 1.) Of the 1,200 scans 5 were considered uninterpretable for tonsil station by one or other of the radiologists. All 5 were in the recumbent trauma group.

Table 1. Grading criteria for tonsil station

<table>
<thead>
<tr>
<th>Tonsil position</th>
<th>Position relative to the basion-opisthion line</th>
</tr>
</thead>
<tbody>
<tr>
<td>+3</td>
<td>&gt;5 mm above</td>
</tr>
<tr>
<td>+2</td>
<td>3 to &lt;5 mm above</td>
</tr>
<tr>
<td>+1</td>
<td>1 to &lt;3 mm above</td>
</tr>
<tr>
<td>0</td>
<td>&lt;1 mm above to &lt;1 mm below</td>
</tr>
<tr>
<td>-1</td>
<td>1 to &lt;3 mm below</td>
</tr>
<tr>
<td>-2</td>
<td>3 to &lt;5 mm below</td>
</tr>
<tr>
<td>-3</td>
<td>&gt;5 mm below</td>
</tr>
</tbody>
</table>

Table 2. Age, gender, and average tonsil station.

<table>
<thead>
<tr>
<th></th>
<th>RNT</th>
<th>RT</th>
<th>UNT</th>
<th>UT</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>300</td>
<td>295</td>
<td>300</td>
<td>300</td>
</tr>
<tr>
<td>Mean age, years</td>
<td>57.4</td>
<td>41.5</td>
<td>54.0</td>
<td>39.7</td>
</tr>
<tr>
<td>Female/male, %</td>
<td>60/39</td>
<td>65/35</td>
<td>57/42</td>
<td>62/37</td>
</tr>
<tr>
<td>Mean tonsil station</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall</td>
<td>1.1</td>
<td>0.7</td>
<td>0.9</td>
<td>0.1</td>
</tr>
<tr>
<td>Male</td>
<td>1.2</td>
<td>0.9</td>
<td>1.1</td>
<td>0.2</td>
</tr>
<tr>
<td>Female</td>
<td>1.2</td>
<td>0.6</td>
<td>0.8</td>
<td>0.0</td>
</tr>
</tbody>
</table>

RNT = recumbent nontrauma; UNT = upright nontrauma; RT = recumbent trauma; UT = upright trauma

Amongst the remaining 1,195 subjects the average age was 41.5 and 39.7 years in the trauma groups, and 57.4 and 54.0 years in the non-trauma groups (recumbent and upright, respectively). The majority of subjects were female in all groups. 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 tonsil station (p = <0.0001; Table 2).

In the two non-trauma groups the tonsils were below the basion-opisthion line in 5.7 and 5.3% of cases in the recumbent and upright groups, respectively. In the trauma groups, the tonsils were
below the basion-opisthion line in 9.5 and 23.7% of cases in the recumbent and upright groups, respectively ($\chi^2=0.0001$)

In this study of 1,200 patients, tonsillar ectopia was identified in 1 in 4 trauma patients versus 1 in 18 nontrauma patients. Upright MRI appears to increase the sensitivity of MRI diagnosis of tonsillar ectopia by more than double [13].

Whether or not tonsillar ectopia results from whiplash trauma is open to question. Chiari 0 was found to be approximately 4 times more prevalent in whiplash-injured neck-pain patients than neck pain patients with no recent history of trauma.

Interestingly, the proportion of upright scans with tonsillar ectopia is approximately the same as the proportion of whiplash-injured patients who go on to experience chronic pain symptoms from their injury [14]. In addition to assessing the degree of cerebellar tonsillar ectopia, MRI can be used to make measurement of the skull base and its relationship to the cerebellum and brainstem as well as its relationship to the cervical spine.

The clivoaxial angle also known as the clivovertebral angle is the angle made by a line drawn along the clivus to the basion and a line drawn down the posterior border of the odontoid peg. It should normally measure between 150 and 180°. (Fig. 4)

This measurement is a good method for assessing the degree of basilar invagination. A decrease in the normal clivoaxial angle can kink the brainstem and cord, compress the contents of the foramen magnum and spinal canal, and cause Chiari malformations. In addition to the spinal cord, the contents of the foramen magnum also include: (1) the vertebral veins, which drain the brain during upright posture; (2) the vertebral arteries, which supply blood to the brainstem, cerebellum and inner aspects of the temporal and occipital lobes of the brain; and (3) the subarachnoid space of the cord, which contains cerebrospinal fluid (CSF) and is continuous with the cisterns of the brain.

The Grabb-Oakes measurement is also invaluable for the assessment of basilar invagination. On MRI, a line is drawn from the basion to the tip of the posterior inferior C2 vertebra. A perpendicular line is drawn from the b–pC2 line to the dura as shown in Figure 5. A value greater than or equal to 9 mm indicates ventral brainstem compression.
To assess for indications of craniocervical instability, Harris’ lines, measuring the basion axial interval and the basion dental interval should be measured. To measure the basion axial interval, a line is drawn along the posterior aspect of the dens and a measurement between this line and the tip of the basion is made (Fig. 6). The basion dental interval is a distance measured between the tip of the basion and the tip of the dens. Both these measurements should be less than 12 mm. If they are greater than 12 mm then occipitoatlantal disassociation has occurred. These measurements are often referred to as the ‘rule of twelve’.

To determine if there is anterior occipitoatlantal disassociation, the Power’s ratio can be measured. This ratio is a distance between the basion and the posterior spinolaminar line of C₁ (BC), divided by the distance between the anterior arch of C₁ and the opisthion (AO; Fig. 7). If the Power’s ratio (BC/AO) is greater than 1, then anterior occipitoatlantal disassociation has occurred.
To assess if there is likely to be basilar invagination, Chamberlain’s line should be drawn between the posterior end of the hard palate to the posterior lip of the foramen magnum, the opisthion (Fig. 8). Basilar invagination is present if the tip of the odontoid peg is more than 3mm above this line.

Another measure of possible basilar invagination is to draw a line from the posterior edge of the hard palate to the most caudal point of the occipital curve. This is referred to as McGregor’s line (Fig. 9). Basilar invagination is likely if the tip of the odontoid process is more than 4.5 mm above this line.
The basal angle of the skull can also be measured when assessing for platybasia, which may occur in association with the Chiari malformation as well as other conditions such as osteogenesis imperfecta and craniocleidodysostosis. The basal angle is the angle formed by a line joining the basion with the centre of the pituitary fossa and a second line joining the anterior border of the foramen magnum with the centre of the pituitary fossa (Fig. 10). The normal range for the basal angle of the skull is between 125 and 145°. Angles of greater than 145° are classified as platybasia. Recently, a modified method for measuring the basal angle has been proposed using the angle formed by a line extending across the anterior cranial fossa to the tip of the dorsum sellae connecting to a line drawn along the posterior margin of the clivus (Fig. 11) [15]. This modified method of Koenigsberg et al, gives measurements that are lower than with the conventional method, in the range of 114–134°.
Acknowledgements

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Figures 3–11: courtesy of Medserena Upright MRI Centre, London, UK.

References