Functional Magnetic Resonance Imaging—Video Diagnosis of Soft-Tissue Trauma to the Craniocervical Joints and Ligaments

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Abstract: Patients suffering from distortion of the cervical spine after an acceleration trauma present problems with respect to the correct diagnostic recognition of the existing injuries. To define instability of the craniocervical junction, attention should be given to the position of the dens and the dimension of its subarachnoid space during the entire rotational maneuver. Our diagnosis via functional magnetic resonance imaging (fMRI) with video did not focus on injuries to the ligamentous microstructure as visualized with high-resolution MRI. Our purpose was to demonstrate the cause of instability of the craniocervical junction by direct visualization during fMRI-video technique. Between December 1997 and March 1999, 200 patients were studied using fMRI on a 0.2-Tesla Magnetom Open. Routine evaluation of the extracranial vertebral circulation by MRI angiography as an additional preinvestigative requirement is recommended. The earliest examination time from injury to MRI evaluation was 3 months and the maximum, 5 years (average, 2.6 years). Among the 200 patients investigated, 30 showed instability of the ligamentous dens complex. Of the same 200, 8 (4%) had a complete rupture and 22 (11%) an incomplete rupture of the alar ligament, with instability signs. In another 45 patients (22.5%), fMRI-video showed evidence of instability, and all these patients had coexisting intraligamentous signal pattern variation, probably due to granulation tissue. Eighty patients of the 200 (40%) had signal indifference without demonstrable video instability signs, and 43 patients (21.5%) showed no evidence of instability and no signal variation in the alar ligaments. On the basis of recognition of instability and the malfunction of the ligaments, the fibrous capsula, and the tiny dens capsula, we now can distinguish between lesions caused by rotatory trauma to the craniocervical junction and those from classic whiplash injury.

Key Words: alar ligaments; functional magnetic resonance imaging; rotatory instability; upper cervical spine

Patients suffering from distortion of the cervical spine after acceleration trauma present problems with respect to the correct diagnostic recognition of the existing injuries involving the cervicocephalic area. This is due to a lack of objective criteria of the established diagnostic modalities. Therefore, correct diagnosis and treatment are difficult. The craniocervical ligaments especially are not visible on plain radiographs. A widened, uneven atlantodental distance implies that the transverse atlantal ligament or the alar ligaments are ruptured or dysfunctional. The diagnosis is merely based on the exact history of the patient and indirect signs during physical examination. What generally is known is that increased axial rotation of the upper cervical spine could cause symptoms such as severe headache, mostly coming from behind, from the authochtonous neck muscle insertion, or from behind the supraorbital region. These symptoms may be combined with subjective complaints such as dizziness, tinnitus, paresthesia, visual disturbance, concentration impairment,

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sleep disturbances, vegetative symptoms, and the inability to ride a bicycle or to control a car in the dark [1,2].

According to Dvorak and Panjabi [3], 25% of all patients with cervical distortion and injury to the soft tissues of the neck suffer from cervical or neck pain (or both) up to 4 to 7 years later, requiring continuing orthopedic, manual, drug, or other therapy [4]. Especially the atlantooccipital plane and, therefore, the socle joint (the body of the vertebrae C2) are regions very vulnerable to indirect trauma to the upper cervical spine and the autochthonous neck musculature [5]. The horizontally oriented facet joints between atlas and axis and their fibrous capsula can be affected by accentuated axial rotation during injury, especially to the alar ligaments. Experience over the last 3 years showed that the surrounding capsula of the dens is an additional component to give stability to the craniocervical junction [6]. Recent case reports [7,8] found that in acute trauma to the head and neck axis, upper cervical ligamentous lesions were present and demonstrable by helical computed tomography (CT) or high-resolution MRI (or both). Our investigations correspond to research by Dvorak and Panjabi [2] and Wolff [5] that soft-tissue damage is highly prevalent in whiplash and rotational traumas and especially after injuries to the upper cervical spine. Our fMRI-video diagnosis did not focus on injuries to the ligamentous microstructure as visualized with high-resolution MRI [9,10]. Rather, our purpose was to demonstrate the cause of instability to the craniocervical junction by direct visualization during MRI-video assessment. The introduction of fMRI on an open magnet [11] renders possible the demonstration of the condition of the ligaments and the atlantoaxial joints on a video loop. A study conducted in 1996 attempted to classify subtypes of alar ligament instability and the different injuries so as to understand better the result of mechanical damage to the ligaments during overstretching [12].

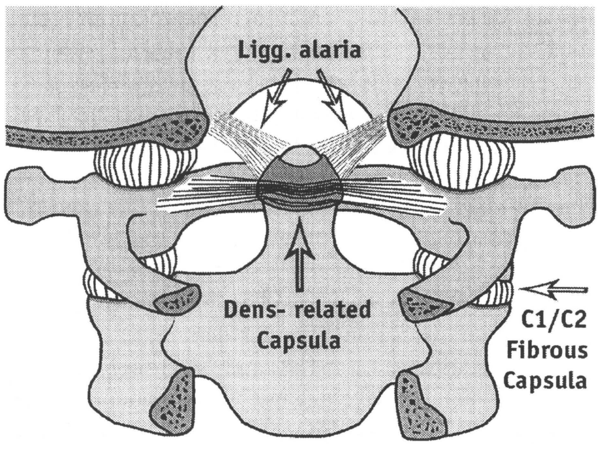
Our study is based on a clinical series of 200 unselected patients, analyzing the signal pattern difference of the ligamentous formation and functional pathology after injuries resulting in capsular and ligamentous instability. The purpose of our investigation was to demonstrate via a standardized video loop the instability in maximum left-to-right obtainable rotation and to show the possible pathology of the craniocervical junction often many years after a whiplash-associated traumatic event affecting levels C1, C2, and C3.

PATIENTS AND METHODS

Between December 1997 and March 1999, 200 patients were investigated with fMRI on a 0.2-Tesla Magnetom Open (Siemens, Erlangen, Germany) using a special device for lateral tilting and transverse rotation. From a total number of 212 patients, we excluded 12 with open penetrating spinal injury, metabolic bone diseases, ankylosing spondylitis, and rheumatoid arthritis; those with generalized connective tissue diseases, especially such elasticity syndromes as Ehlers-Danlos syndrome and Marfan's syndrome; and children under the age of 18 years. We investigated 200 patients (96 female, 104 male) with a history of traumatic injury involving the upper cervical spine. The mechanism of injury included high-speed trauma by automobile accident and automobile-pedestrian collision (n = 188) and fall from high elevation (n = 12). The average age of the patients was 36 years (range, 18–52). The earliest examination time from injury to fMRI evaluation was 3 months and the maximum, 5 years (average, 2.6 years). Most patients had undergone plain radiography, and some had either thin-slice helical CT or high-resolution MRI under static conditions.

All the MRI studies were performed on a 0.2-Tesla Magnetom Open. These patients underwent MRI angiography of the cervical intervertebral arteries before the functional investigation was started. Where necessary, monitoring of heart rate and respiratory function during MRI investigation was performed using a fiberoptic pulse oximeter (Nonin 8600 FO, Mediquip, Germany). Furthermore, visual monitoring was continuous by direct view of the patient. The method to investigate in an open magnet was based on familiarity with clinical manual therapy, tilting the neck step by step to the right and left and, under conditions of maximal rotation, to the right and to the left side by an experienced physician. In our series, no anesthesia was given. The procedure could be interrupted on loss of consciousness or blockage to the upper cervical spine (or both) with possible irritation to the vertebrobasilar system. The details of the MRI parameters and characteristics were reported in 1996 [11]. Circular surface coils differing in diameter were used to improve the anatomical resolution at the three target points. Thin slices, mostly between 4 and 5 mm only, oriented to the exact location of the alar ligaments, either oriented horizontally or off-axis, were applied. Several pulse sequences were used, including fast-spin echo (for the motion video loop) and gradient echo as T_1- and T_2- weighted images to delineate exactly the fibrous C1-2 capsula and the surrounding dens synovial capsula. No three-dimensional gradient sequences with secondary reconstruction were used. To characterize the instability patterns of the craniocervical joint, especially of the dens, the small surrounding synovial capsula, and the alar ligaments (Fig. 1A), we used two criteria of malfunctioning of the dens: the left-to-right tumbling or the anterior-posterior

A



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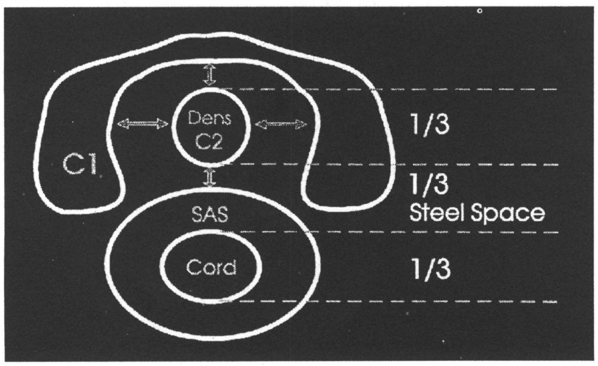
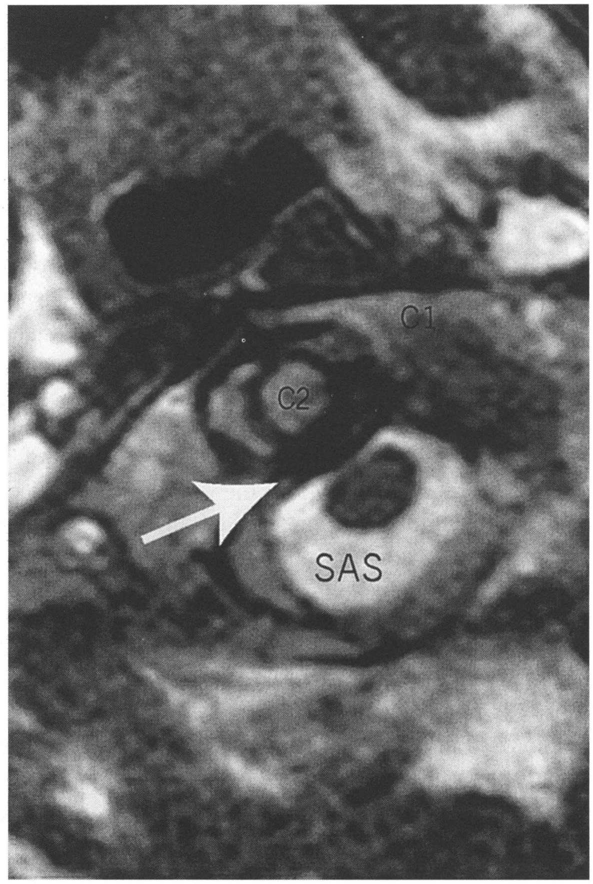


Figure 1. (A) Schematic of the craniocervical region. Note instability components (*arrows*). (B) Schematic of the 3/3 Steel spaces [23]. Note the instability directions of the craniocervical region (*arrows*). (*SAS* = subarachnoid space.)

A



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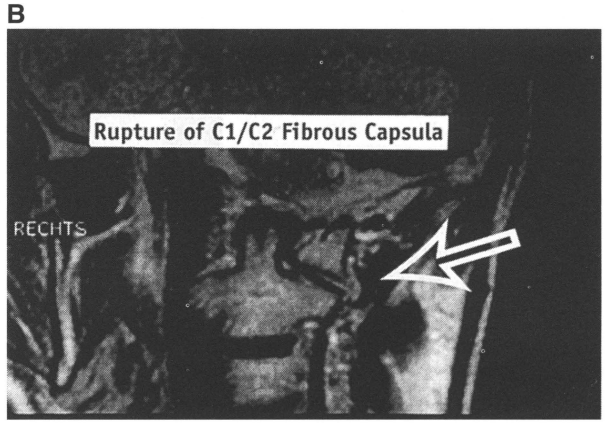

Figure 2. (A) Axial functional magnetic resonance imaging with maximum right rotation and spinal cord contact (*arrow*), indicating instability of the dens and the alar ligaments. (*SAS* = subarachnoid space.) (B) Coronal functional magnetic resonance imaging with absence of fibrous capsula membrane (*arrow*) and resulting spinal vessel contact, indicating instability of the dens.

movement of the dens—"dancing dens"—during fMRI-video documentation and the total loss of subarachnoid space leading to a spinal cord contact (Fig. 1B).

To define instability of the craniocervical junction, attention should be given to the position of the dens and the dimension of its subarachnoid space during the entire rotational maneuver. The types of ligamentous lesions and the recognized instability were reviewed with respect to the patients' neurootological and orthopedic or manual clinical presentation. Forty-two patients with documented injuries of alar ligaments and signs of instability were referred to a neurosurgeon.

RESULTS

Among the 200 patients investigated, 30 (15%) demonstrated an instability with an enormous left-to-right shifting of the dens or a tumbling dens instability (Fig. 2A). Of these 200 patients, 8 (4%) had a complete rupture and 22 (11%) an incomplete rupture of the alar ligament. In our previous study [12], the incomplete ruptures have been listed as types IIa and IIb. In this group, only 2 of 30 had an associated periostal dens pathology. Of eight patients, four with ruptured alar ligaments showed coexisting intraligamentous signal changes and possible elongation of the transverse ligament but no evidence of complete rupture. In the video loop, a contralateral alar ligament malfunction was postulated, and nearly one-half of those exhibiting instability showed possible traumatic pathology of the C1-2 or C2-3 fibrous capsula (Fig. 2B), resulting in subluxation positions of C2 vertebrae.

All those in the second group, consisting of 45 of the 200 patients (22.5%), showed evidence of instability in the fMRI-video. However, they had only intraligamentous signal pattern variation, probably due to granulation tissue. Sometimes, in addition, we found a possible fibrous capsula pathology probably due to rupture of C1-2 and resulting in a subluxation position of C2 vertebrae. In this group, we found a correlation between anterior-posterior dens movement and a periostal dens pathology in 18 of the 45 patients.

The third patient group of 123 (61.5%) had no significant signs of instability, neither a left-to-right tumbling dens nor a loss of subarachnoid space during rotational maneuvers. Of the 200 patients, 80 (40%) had signal indifference of one or both alar ligaments in more than one fMRI scan. The number of possible fibrous capsular traumas was 28 of 80 (14% of 200) patients. Only 43 of the 200 (21.5%) patients of the third group showed no evidence of instability of the craniocervical junction and no signal variation in the alar ligaments. In this last group were two patients (1%) with noted bony dens variation.

DISCUSSION

This study is based on fMRI-video diagnosis to evaluate patients with craniocervical instability with loss of normal function of the ligamentous dens complex after nonpenetrating cervical spine trauma. When one alar ligament is injured, the main mechanism of motion restriction—that of axial rotation—no longer is limited. Especially in rear-end car accidents with a whiplash mechanism and a rotational component, the ligaments would be most vulnerable when the head is initially flexed and rotated [13]. We do not perform rotational CT scans because of the patients' limited capability of movement. CT and MRI are limited in their ability to visualize cervical side bending, which would show the capsular pathology, and controlled maximum rotation. We perform helical high-resolution CT only to observe former fractures of the odontoid process or of the axis and of the occipital condyles [14,15]. In all patients, the MRI evaluation first should exclude vertebral artery pathology because of the risk of restricted blood flow through the contralateral vertebral artery during passive rotation to the opposite side. Patients with a known history of vascular insufficiency underwent standby monitoring to minimize the drop-attack risk. Through direct controlled posturing of patients during the rotational maneuvers, we were able to recognize early irregularities of patients' discomfort.

A previous study showed that 7 of 95 patients (7%) who underwent fMRI of the upper cervical spine had unilateral vertebral artery blood flow difference, in some cases suggesting unilateral hypoplasia [12]. We concur with Willauschus et al. [16] that only a low incidence of complete ligamentous rupture appears in accident victims; among our patients, the figure was 4%. However, we do not agree with those investigators that a complete rupture of the alar ligament always is associated with a bone fracture. In accordance with Dvorak et al. [13] and Wen et al. [17] and the recent work of Obenauer et al. [18], we postulate that the number of alar ligamentous traumas without any bone pathology is higher then estimated. In our series, only 20 of 200 patients (10%) had ligamentous injuries combined with dens periostal trauma pathology. We also concur with Obenauer et al. [18] and Crisco et al. [19] that first a rupture of the alar ligaments occurs and that only after complete separation of the alar ligaments might a rupture of the transverse atlantodental ligament occur, as shown by Dickmann et al. [20]. The dens fractures and the ligamentous avulsion fractures are not common in rotational traumas [13,18]. The alar ligaments are injured mainly 1 cm before the dens periostal insertion [18,21] or suffer instability, because they are particularly vulnerable, given that they are composed mainly of collagenous fibers and contain few elastic fibers [22]. They are relatively weak as compared to other ligaments [3,13]. The strength of a nonfunctional ligament cannot be restored.

One unresolved diagnostic imaging problem is an alteration of signals in patients with functionally normal craniocervical ligaments. On the basis of the observation of incomplete rupture to ankle and joint ligaments, we can anticipate that scar formation is due to an "inhomogeneous band mass" and can result in an asymmetrical pattern of the ligamentous structures. In the future, increasing our understanding of osseous, ligamentous, capsular, and facet joint variations at the craniocervical junction is necessary. Physicians must bear in mind the embryological vascular anatomy and its variants, as well as the defined elasticity syndromes, before an fMRI investigation is performed (e.g., in an open system with manually controlled movements). In 61.5% of our patient group, we can demonstrate stability; 40% showed a signal pattern difference to the alar ligaments, and 21.5% showed intact stability and alar ligamentous signal continuity. In this large group, the patients may have nociceptive input failure among the fibrous capsula, the synovial membranes of the affected facet joints, and the muscular interaction of the cervicocephalic region [5].

We must analyze the signal intensity pattern of the alar ligaments and the pathology around the fibrous capsula and demonstrate the instability to the surgeon by fMRI-video technique. To define instability of the craniocervical junction, attention should be given to the position of the dens and the dimension of its subarachnoid space [23] during the entire rotational maneuver. A routine brain MRI and, if possible, an anteroposterior cervical MRI investigation under flexion and extension conditions should be performed before surgery of the upper cervical spine [24].

On the basis of our results and as compared to other functional studies [17], fMRI-video diagnosis can be recommended as a method to demonstrate the instability of the craniocervical junction and to understand the real impact of biomechanical power to the cervicocephalic region. However, the true basis of instability will have to be clarified by controlled and coordinated studies undertaken by investigating physicians (especially neurootologists) and surgeons and particularly by follow-up studies.

CONCLUSION

fMRI is a noninvasive and a nonradiated special investigation to rule out the instability of the craniocervical junction and traumatic pathology to the fibrous capsula and ligaments. Routine evaluation of the extracranial vertebral circulation by MRI angiography as an additional preinvestigative requirement is recommended. On the basis of the recognition of an instability of the craniocervical junction, especially a malfunction of the alar ligaments and fibrous capsula, we now can distinguish between lesions due to rotatory trauma to the craniocervical junction and those from classic whiplash injury. We anticipate that the fMRI-video technique can select the patient group for the most appropriate neurosurgical intervention after severe traumatic soft-tissue rupture.

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