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Imaging in Whiplash-Associated Disorders

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Abstract

Whiplash, a term describing the severe acceleration and deceleration forces applied to the head, craniocervical junction and cervical spine during trauma, is one of the most frequent mechanisms of injury to the craniocervical junction (CCJ). The craniocervical junction is a complex region at the transition of the cranium and the cervical spine, essential for maintaining craniocervical stability. In whiplash injuries, the craniocervical junction may be compromised due to underlying ligamentous or, less frequently, osseous, intravertebral disc and/or muscular lesions. Imaging is crucial in detecting acute lesions but may also play a role in the follow-up of chronic pathology as soft tissue lesions and progressive disc pathology could contribute to a whiplash-associated disorder.

Keywords

► Cervical spine
► Craniocervical Junction
► Magnetic resonance imaging
► Computed tomography
► Whiplash injuries

1. Introduction

The term "whiplash" was first introduced by H. Crowe in 1928. It was defined after the movement the head makes in a motor vehicle accident, causing injuries to the cervical spine and associated soft tissues. Since then, many variants of the term have been used in literature, mainly covering cervical injuries and symptoms. Even in common popular vocabulary, it has been used as an emotional term, especially in litigation. In order to homogenize terminology, the Quebec Task Force defined the term 'whiplash' as "an *acceleration–deceleration mechanism of energy transfer to the neck. It can result from rear-end or side-impact motor vehicle collisions but can also occur during diving or other mishaps. The impact may result in bony or soft tissue injuries (whiplash injury), which in turn may lead to a variety of clinical manifestations (Whiplash-Associated Disorders–WAD)".* [1] The term "Whiplash Associated Disorders" was introduced as the umbrella term for symptoms affecting the neck. Acute whiplash injuries, and especially lesions of the ligamentous soft tissues, gained a lot of attention as these can result in rotatory hypermobility or instability of the upper cervical spine. [2] Whiplash injuries are common, with an estimated incidence of 4 per 1000 inhabitants. A prevalence of 7.7% and 9.6% in men and women respectively, was reported by Kumagai.[3] Whiplash injuries typically occur in a young population, with a reported mean age of 38 years.[4] Whiplash injuries are in 85% of cases caused by rear-end collisions in vehicle accidents but may also be caused by other mishaps causing an acceleration-deceleration force. [5]

2. Symptomatology

The symptomatology in whiplash-associated-disorders is varying and patients may present with a myriad of symptoms. Patients with whiplash-associated-disorders most frequently present with neck stiffness, cervicalgia, brachialgia and occipitalgia. Kasch et. al. reported that headache was found in 85,4% of patients with acute whiplash injury. [6,7]

Whiplash-related headaches appear to be short-lasting, most frequently presenting as tension-type headaches and cervicogenic headaches.[8] Neck pain is the most prevalent symptom and is usually present immediately or within 24 hours after impact. Blurred vision, tinnitus, vertigo, or auditory dysfunction may be present due to lesions of the vertebral artery, cranial nerves, or lesions in the inner ear.[9] Other common neurological symptoms may include paraesthesia, sensation of numbness and tingling. Visual disturbances such as diplopia, defective accommodation, and Horner's syndrome may be present in lesions of the sympathetic pathway.[10] More commonly in late-whiplash syndrome, psychological symptoms must also be considered as they may lead to PTSS or depression. [11] The Quebec Task Force created a clinical grading system for whiplash-associated disorders. They primarily included neck sprain, musculoskeletal lesions, and neurological signs (►**Table 1**). The vast majority of patients is either grade 1 or grade 2. It should be noted that whiplash-associated disorder is a clinical diagnosis.

Table 1. Clinical grading of whiplash injuries according to the Quebec Task Force of whiplash-associated disorders

Grade	*Symptoms and signs*
0	No neck pain, stiffness, or any physical signs are noticed
1	Neck complaints of pain, stiffness, or tenderness only but no physical signs are noted by the examining physician
2	Neck complaints and the examining physician finds decreased range of motion and point tenderness in the neck.
3	Neck complaints plus neurological signs such as decreased deep tendon reflexes, weakness, and sensory deficits
4	Neck complaints and fracture or dislocation, or injury to the spinal cord.

3. Injuries to the craniocervical ligaments

The craniocervical junction (CCJ), also known as the occipito-atlanto-axial complex, is a complex region at the junction of the cranium and the cervical spine. It contains several important anatomical structures and joints, including the atlas (C1), the axis (C2) and the occipital bone of the skull. This anatomical region is crucial as it provides structural support to the head and neck and allows for a wide range of motion. Alongside the osseous structures, the associated ligamentous complex is essential in providing structural stability of the CCJ. [12] The anatomy of the ligamentous structures will be discussed in detail in section 3.2.

The imaging modality of choice for ligamentous injuries in general, is magnetic resonance imaging (MRI), as it provides a superior contrast resolution, and this is especially true in ligaments that are located deeper as those of the CCJ.[13] MRI not only has an inherent higher sensitivity for evaluating ligaments, but the same holds true for other soft tissue injuries such as intervertebral discs, muscles and spinal cord. In moderate to high-risk cases, there is also a role for MRI to assess possible spinal cord injury. In low-risk cases, there is some controversy on the role of imaging. [14,15] Alongside routine MRI sequences for the cervical spine (sagittal TSE T2; sagittal TSE T1; sagittal TIR T2; para-axial 3D GRE T2), proton-density 3D turbo/fast spin echo with variable flip-angle distribution should be utilized in assessing the craniocervical junction (3D TSE PD, SPACE/CUBE/VISTA). [16] CT and plain film X-ray can be used to detect fractures and may indicate serious ligamentous injury in cases of avulsion fractures and/or lateral atlantodental interval asymmetry.

3.1 Imaging interpretation and grading

As mentioned above, ligaments of the CCJ should be assessed with MRI. PD-hyperintensities within the ligament or a focal asymmetry in PD-signal represents injury to the ligamentous fibres. However, it should be noted that these PD-hyperintensities can also be attributed to age-related changes, as described by Peters et. al. They reported that 58% of asymptomatic patients showed degeneration of at least one ligament of the CCJ, probably due to normal ageing or repetitive microtrauma. High-grade anomalous changes and multiligamentous involvement had a positive correlation with age. [17] As such, we suggest using the following grading scale in ligaments of the CCJ, especially in the transverse ligament as this ligament is susceptible to age-related changes (►**Table 2**). Most whiplash patients, however, are relatively young and we expect less degenerative changes in this age group making grade 1-3 changes in the CCJ ligaments more suspect of traumatic lesions.

Table 2. MRI grading criteria for changes to the ligaments of the craniocervical junction on PD-WI	
Grade	*Symptoms and signs*
0	Normal thickness with homogeneous low signal
1	Normal thickness with focal or diffuse high signal
2	Focal or diffuse thinned ligament with or without high signal
3	Focal ruptured ligament or indistinguishable ligament

3.2 Ligaments of the craniocervical junction

3.2.1 Transverse ligament

The transverse ligament is the primary stabilizing ligamentous structure of the CCJ. It is this the strongest and thickest ligament of the CCJ.[18] It is approximately 20mm in length. Together with the superior and inferior crura, it forms the cross-shaped cruciate ligament of the CCJ. The transverse ligament is found posteriorly of the odontoid process (►**Fig. 1**). It attaches bilaterally to the lateral process of the atlas (►**Fig. 2**). Due to its anatomical attachment, the odontoid process is fixed against the odontoid facet on the anterior arch of the atlas, which has a fibrocartilaginous component to facilitate movement. Forming this 'bridge', it prevents the odontoid process from moving posteriorly/the atlas moving anteriorly with secondary spinal narrowing and possible compression the spinal cord. The transverse ligament allows axial rotation which in turn is opposed by the alar ligaments, which restrict extensive rotation. [19] It restricts both flexion and the anterior displacement of the atlas. [2] Due to its biomechanical properties it only allows 3-5 mm subluxation of the atlas. Injuries of the transverse ligament mainly occur in the central part of the ligament but may also be present near the insertion at the lateral process of the atlas. In severe injuries, avulsion injury of the bony tubercle is possible. The vertical part of the cruciform ligament (superior and inferior crura) is a thin structure and doesn't provide significant craniocervical stability. [19,20]

As the transverse is the primary stabilizing ligament of the craniocervical junction, it should be carefully inspected. On MRI, the vertical part of the cruciate ligament (containing the superior and inferior crura) is rarely visualized. The horizontal part of the cruciate ligament is best seen on coronal and sagittal images as a thick hypointense band on PD- sequences. Associated avulsions of the medial tubercle of the atlas can be seen in Gehweiler type IIIb fractures. Bone contusions and fractures present with bone marrow oedema, which is clearly seen on STIR sequences.

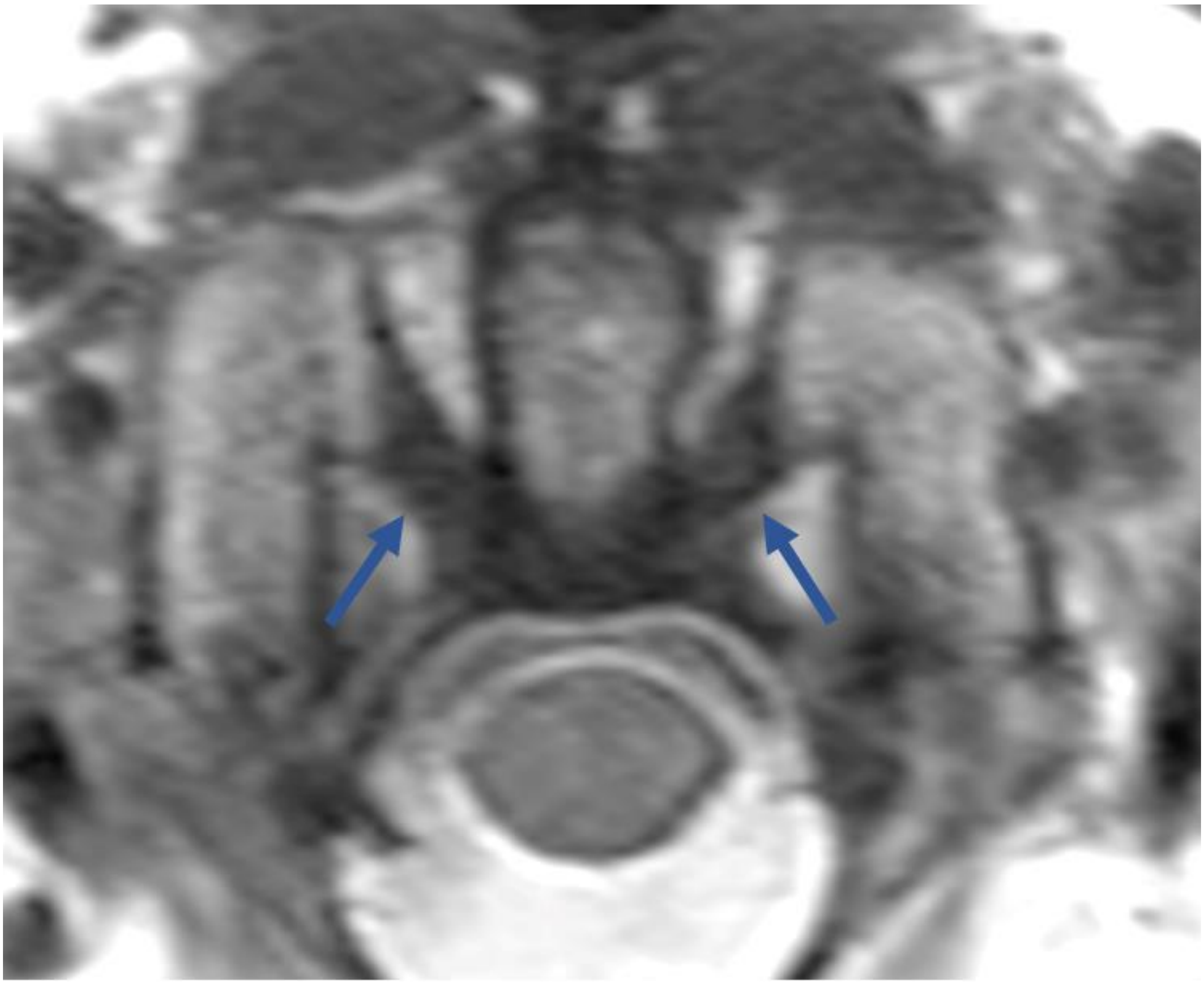


Figure 1: MRI axial 3D PD-weighted image of the normal transverse ligament. This image is a reconstruction in the plane of the transverse ligament (arrow). It should be noted that the parasagittal plane is preferred to assess the transverse ligament (see Fig. 2).

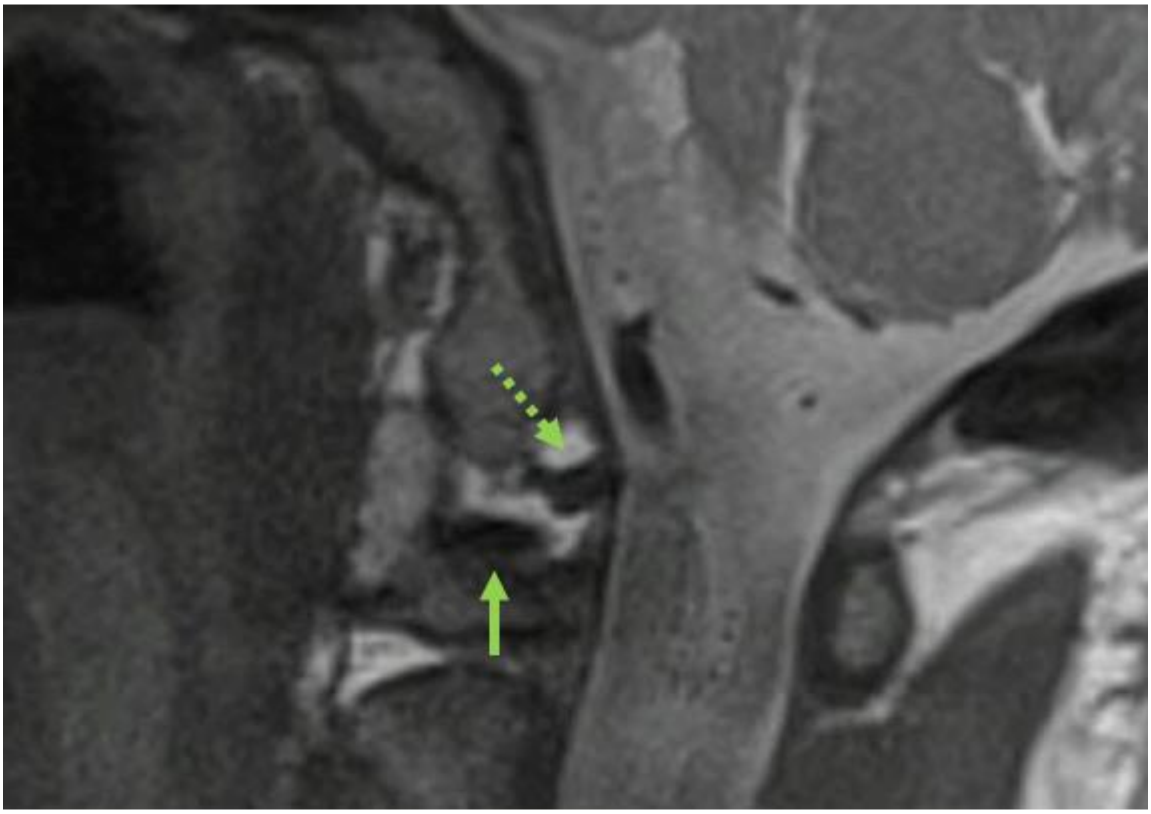


Figure 2: MRI parasagittal 3D PD-weighted image of the craniocervical junction. This image shows a normal anatomy of the alar ligament (dashed arrow) and the ipsilateral transverse ligament (arrow). Note the symmetrical hypo-intense signal intensity of the normal alar and transverse ligaments. Asymmetrical PD-hyperintensities should raise suspicion of underlying pathology. Also note that both ligaments are comparable in cross-section area.

3.2.2 Alar ligaments

The alar ligaments are next to the transverse ligament one of the main stabilizing ligaments of the craniocervical junction. The alar ligaments originate from the posterolateral sides of the odontoid process and extend upward and laterally to attach to the medial surfaces of the occipital condyles (►**Fig. 3**). However, the alar ligaments may also run horizontally. The mean length of the alar ligaments was found to be 11-13mm and most frequently tube-shaped.[21] The alar ligaments restrain rotation, restrict side-to-side motion and attach the dens to the skull. On CT, fractures of the medial aspect of the occipital condyle can be seen in severe trauma which causes extensive rotation/contralateral bending. According to the Anderson and Montesano classification for occipital condyle fractures, this avulsion fracture is classified as a type III lesion. This finding is important, as these lesions may require a surgical intervention. In type I and II lesions, the alar ligaments are intact. [22] The alar ligaments can be visualized on MRI as a bilateral hypointense band, seen on coronal images as a classical V-shaped morphology. On sagittal images the normal alar ligaments are comparable in thickness to the transverse ligament which runs almost parallel and very nearby (►**Fig. 2**). Sagittal images are best to detect hyperintensities/lesions in the ligament.

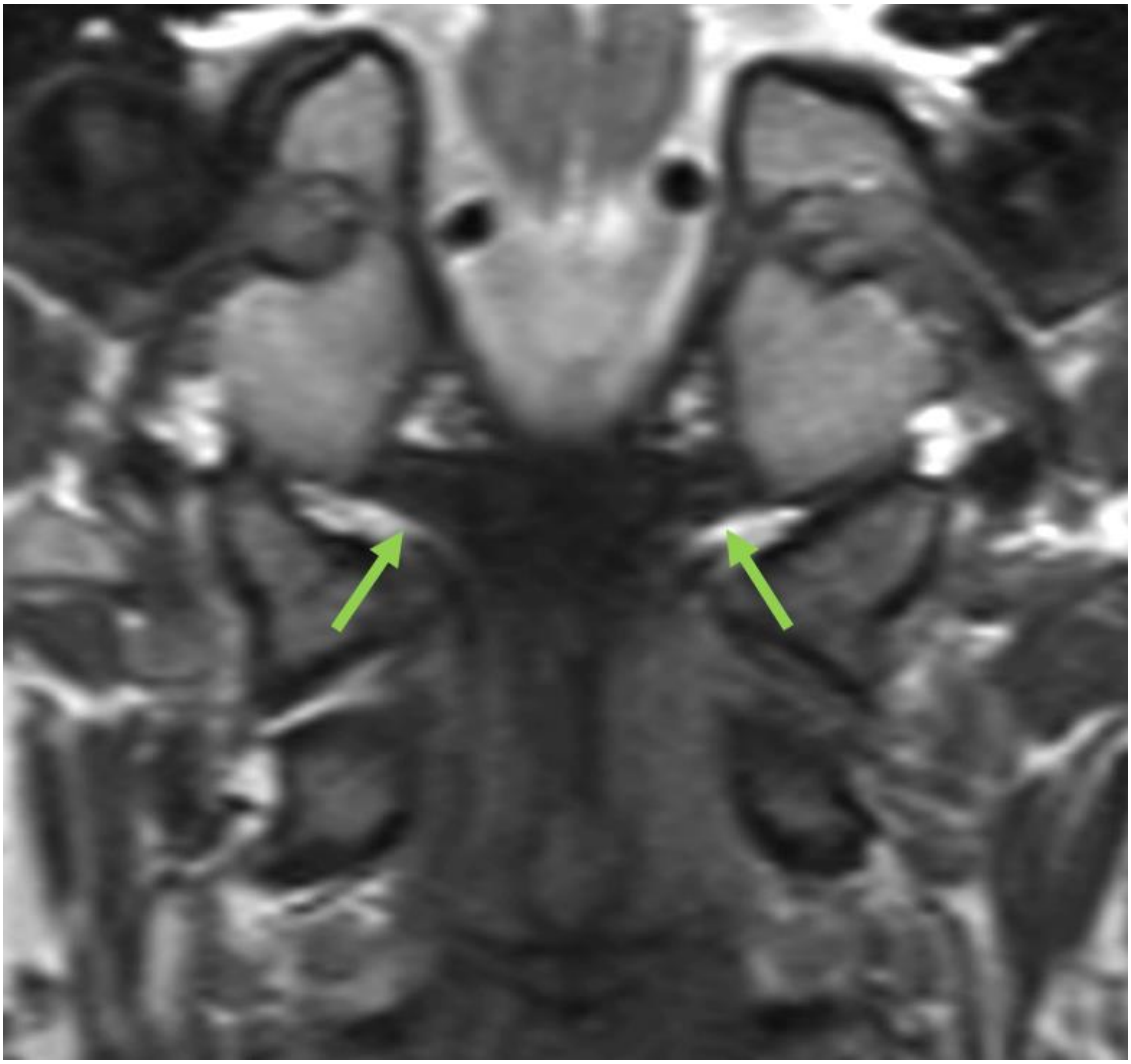


Figure 3: MRI paracoronal reconstructed 3D PD-weighted image of the craniocervical junction. This image shows the normal appearance of the alar ligaments (arrows). The alar ligaments can be visualized on MRI as a bilateral hypointense band, seen on coronal images as a classical V-shaped morphology, but usually run more horizontally as in this case

3.2.3 Tectorial membrane

The tectorial membrane is a dense, fibrous band of tissue that is attached to the body of the axis and extends superiorly along the anterior surface of the foramen magnum, where it firmly coheres with the dura mater of the clivus (**►Fig. 4**). It is a continuation of the posterior longitudinal ligament, which runs along the anterior surface of the spinal canal. It also has a lateral part that joins the atlanto-occipital joint capsules (Arnold's ligament). [23,24] It is the only ligamentous structure of the craniocervical junction that adheres to the dura mater. [25] The mean thickness of this membrane was reported to be 1 mm by Tubbs et. al. [23] Its main biomechanical function is to preserve stability in flexion-extension. More importantly, it prevents the odontoid process from impinging into the spinal canal. It forms the posterior wall of the supra-odontoid space or "apical cave". [12] This space contains other the abovementioned alar and apical ligaments, as well as the Barkow ligament. The tectorial membrane is visualized on MRI in the sagittal plane as a hypointense stripe that runs from the axis body to the posterior surface of the clivus. Fiester et. al. described injuries to the tectorial membrane based on location and morphology: retroclival stripping (type I), subclival disruption at the basion (type IIa) or the odontoid process (type IIb). Thinning or stretching was described as type III. [26,27]

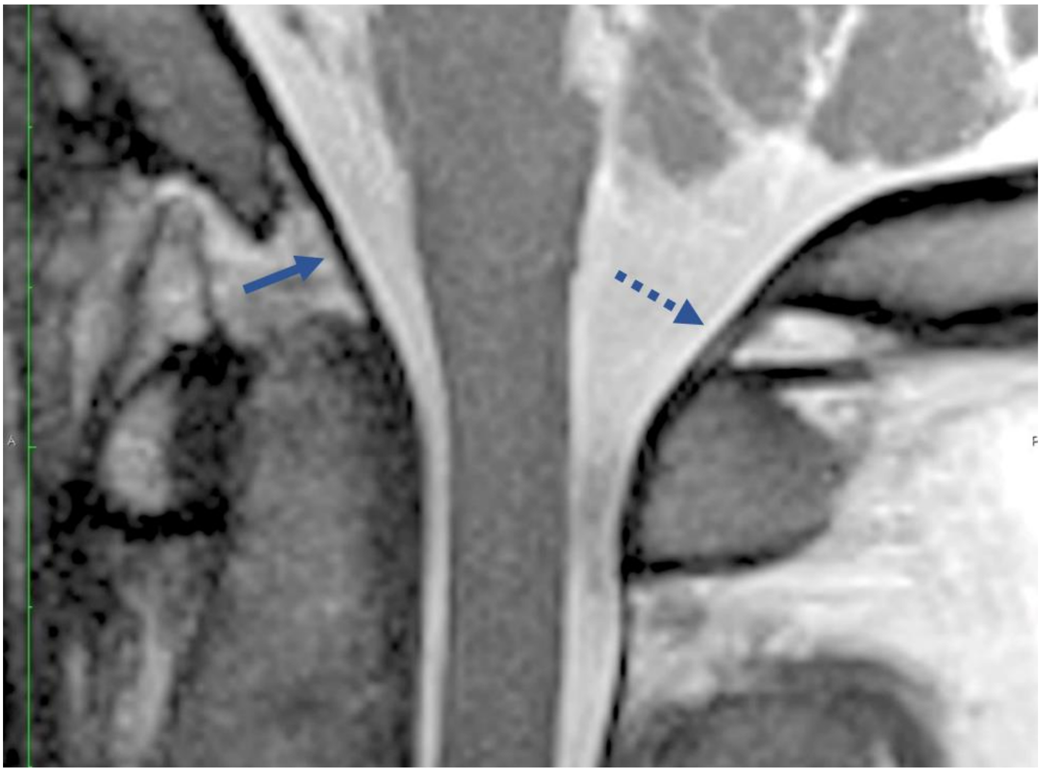


Figure 4: MRI sagittal 3D PD-weighted midline image of the craniocervical junction. This image depicts the tectorial membrane (arrow) and the posterior atlanto-occipital membrane (PAOM) (dashed arrow). Note the continuation of the tectorial membrane on the clivus, as it adheres with the adjacent dura mater.

3.2.4 Anterior atlanto-occipital membrane (AAOM)

The anterior wall of the supra-odontoid space is delineated by the anterior atlanto-occipital membrane (AAOM) or ligament. It is tightly composed of collagenous fibres and extend superiorly from the superior edge of the anterior arch of the atlas to the anterior surface of the foramen magnum. The longus capitis muscle runs superficially from this membrane. As well as the other ligaments of the CCJ it helps stabilize the atlanto-occipital joint and prevents hyperextension. The AAOM is best visible on sagittal images on MRI.

3.2.5 Posterior atlanto-occipital membrane (PAOM)

The upper edge of the posterior arch of the atlas houses the origin of the posterior atlanto-occipital membrane (PAOM) or ligament. As a blade, it connects the atlas with the posterior surface of the foramen magnum **(►Fig. 4**). It is thought to be the continuation of the ligamentum flavum of C1. The strongest fibres of the membrane are medially located, whereas the lateral fibres connect with the atlanto-occipital joint capsule. Within these fibres, there is a small defect wherein the vertebral artery runs through. [27] Unlike the AAOM, the PAOM will consequently prevent hyperflexion and impingement of the atlas on the cervicomedullary junction. The PAOM is best visible on sagittal images on MRI.

3.2.6 Apical ligament

The apical ligament is a fibrous band that connects the tip of the odontoid process to the basion (anterior border of the foramen magnum), superior to the condylus tertius (►**Fig. 5**). It is centred in the midline and creates a triangular space, enclosed by the alar ligaments, which run laterally. Studies have shown a length varying from 10.5 to 11.5 mm and a width from 3 to 5 mm.[28] Tubbs et. al. found an absent apical ligament in 20% of the cadavers, endorsing the fact that this ligament isn't a primary stabilizer of the craniocervical junction. It has been suggested that the apical ligament is best described as a vestigial structure in the CCJ and shouldn't be classified as a ligament that needs to be routinely looked at by radiologists. [29] Due to slice thickness on MRI, it is difficult to assess.

Figure 5: MRI sagittal 3D PD-weighted midline image of the craniocervical junction. This image depicts a normal anatomy of the apical ligament (arrow). It connects the tip of the odontoid process to the anterior margin of the foramen magnum (i.e., the basion), superior to the condylus tertius. The tectorial membrane (dashed arrow) and posterior atlanto-occipital membrane (PAOM) (asterisk) can also be seen.

3.2.7 Barkow ligament

The Barkow ligament is a thin fibrous stripe within the craniocervical junction that gained little attention in anatomy of the craniocervical junction. It runs horizontally and anteriorly from the tip of the odontoid process and attaches bilaterally to the lateral edges of the foramen magnum. Tubbs et. al. showed that the Barkow ligament appears to resist extension of the atlantooccipital joint and may be synergistic with the anterior atlantooccipital membrane. [30] It is part of the 'apical cave'. Due to its thin structure, it may be difficult to assess on MR-imaging. It is however best visible on sagittal images. (►**Fig. 6**).

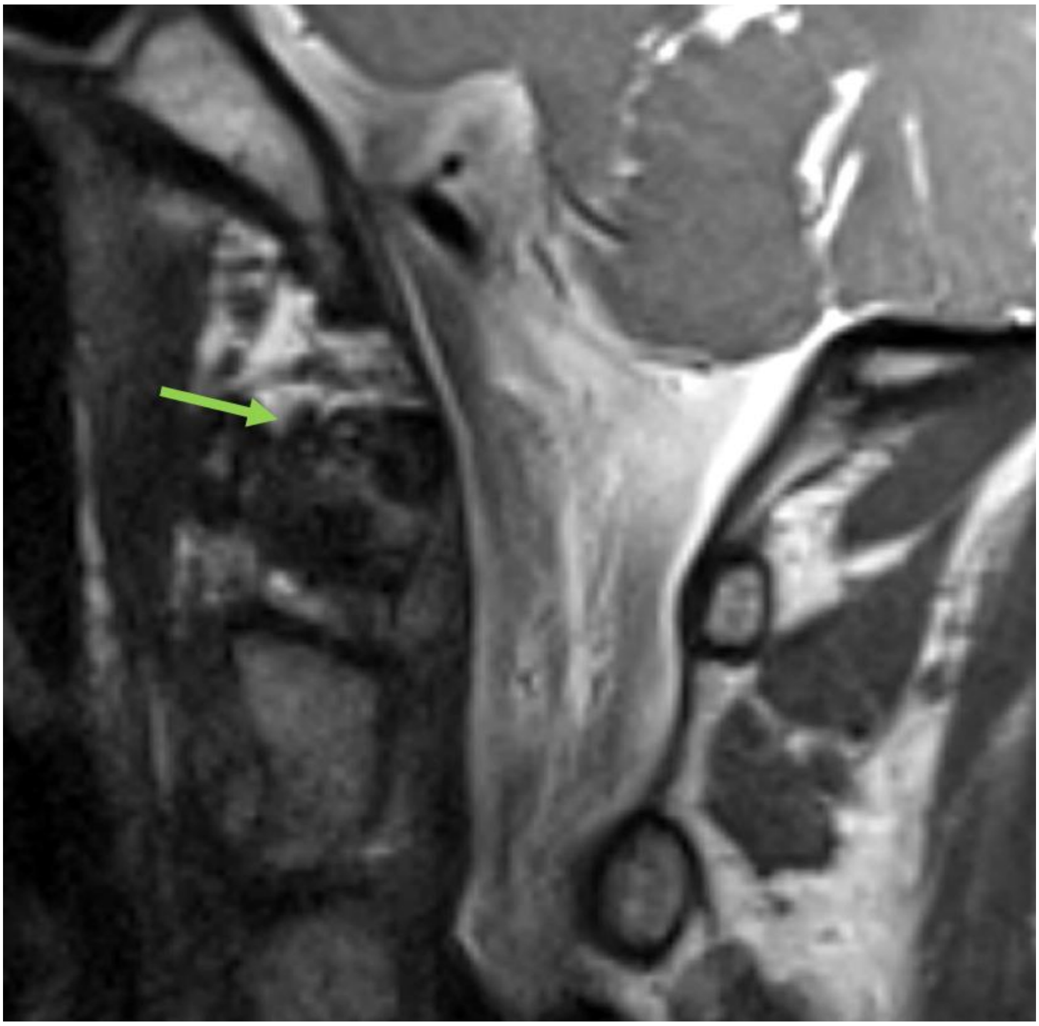
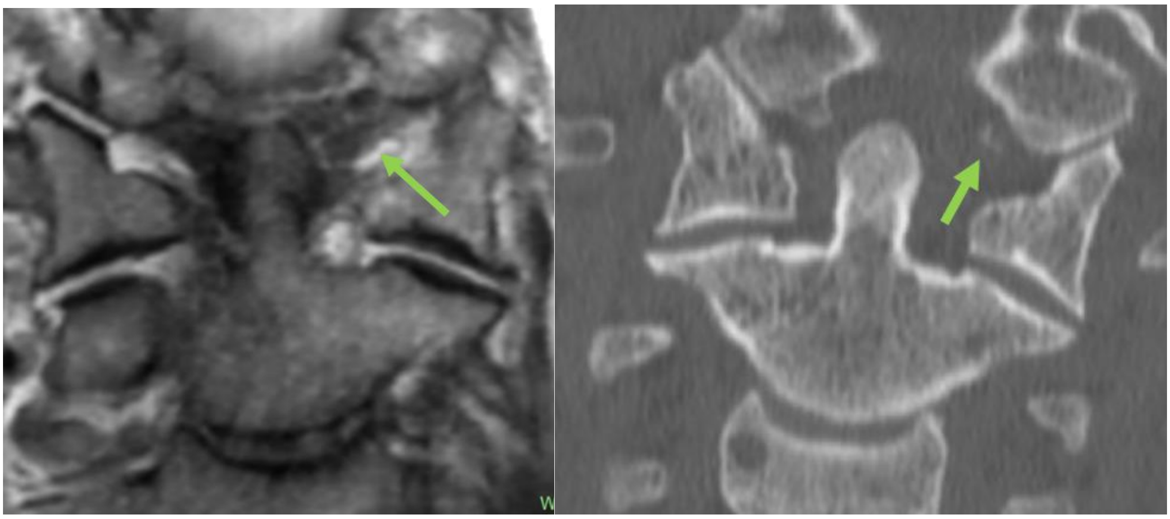
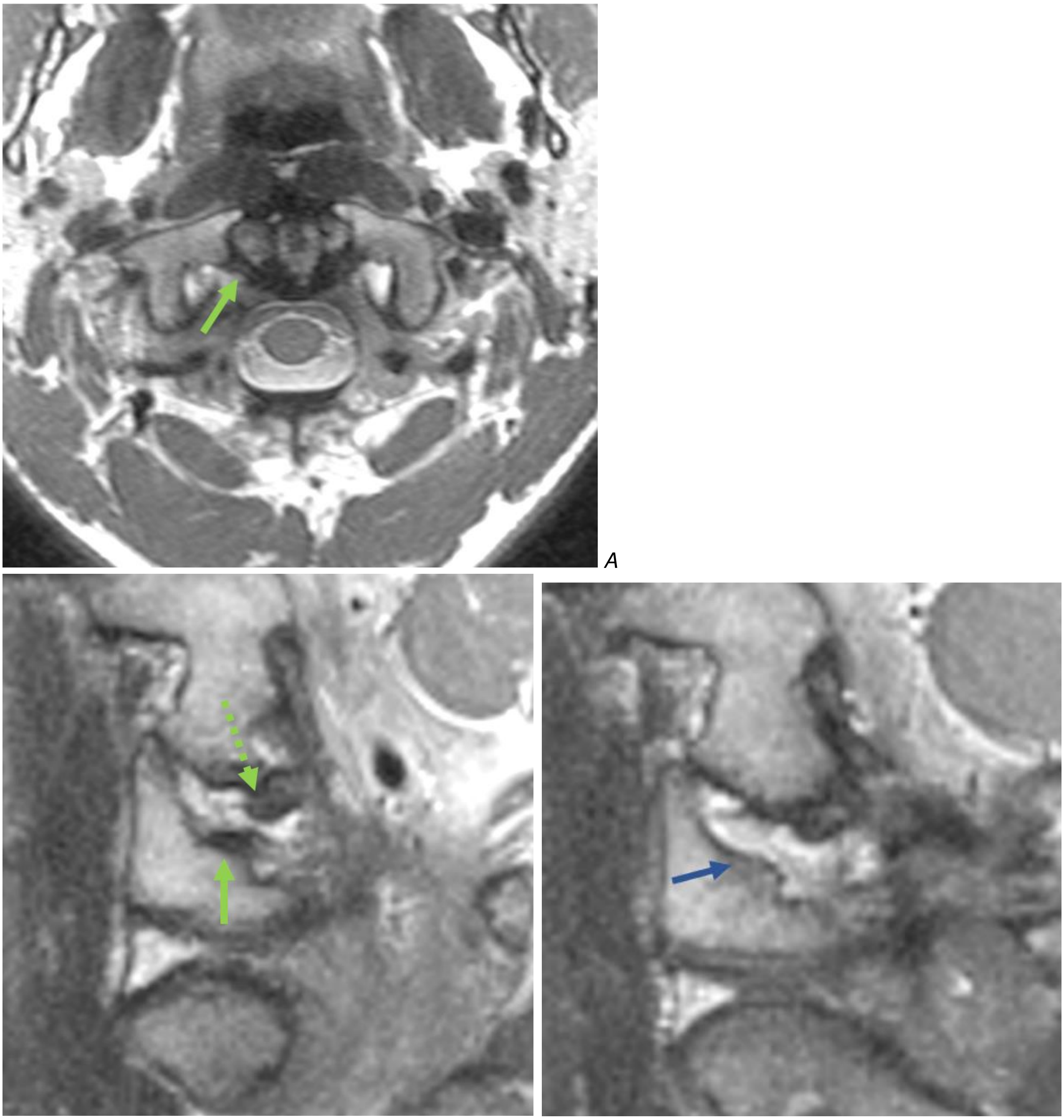


Figure 6: MRI parasagittal 3D PD-weighted image of the craniocervical junction. Normal anatomy of the Barkow ligament. (arrow).



A *B*

*Figure 7: Patient with severe whiplash injury. **(a**) MRI coronal reformatted 3D PD-weighted image of the craniocervical junction shows an asymmetrical PD-hyperintensity within the left alar ligament with thinning of some of the fibers (grade 2 lesion) (arrow). (**b**) CT-scan in the same patient shows avulsion fracture of the occipital condyle and asymmetric position of the odontoid process. (arrow)*



A

B

C

*Figure 8: Patient with whiplash injury. (**a**) MRI axial 3D PD-weighted image of the craniocervical junction shows an asymmetrical PD-hyperintensity within the right transverse ligament (arrow). (**b**) This image shows a normal anatomy of the transverse ligament (arrow) and the ipsilateral alar ligament (dashed arrow). Note the symmetrical signal intensity of the alar and transverse ligaments. (**c**) Grade II lesion of the right transverse ligament with* thinning of the ligament and severe PD-hyperintensity (arrow).

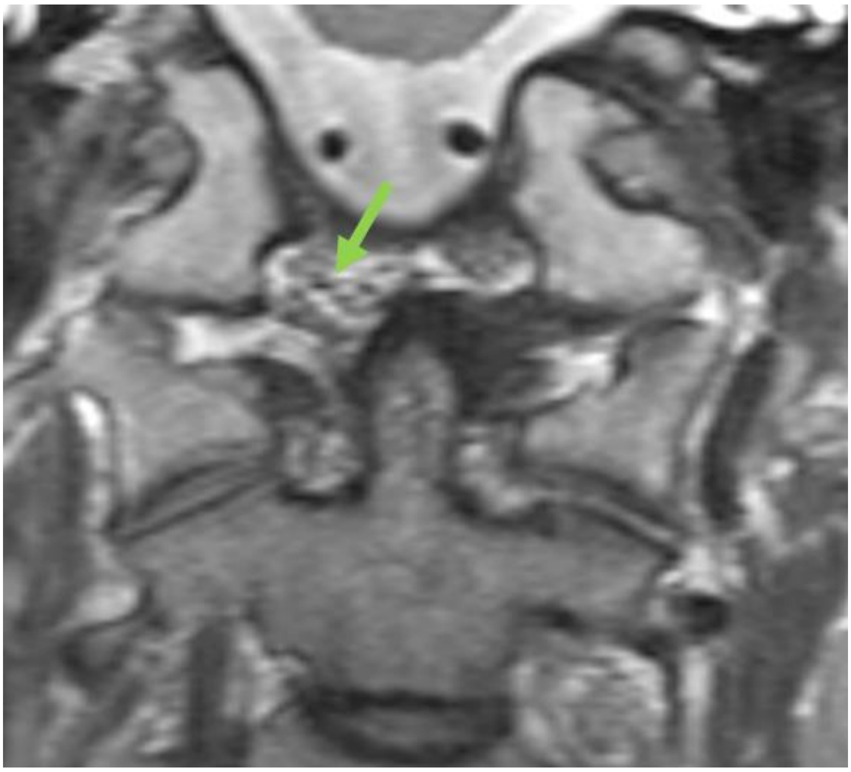


Figure 9: Patient with severe whiplash injury. MRI coronal reformatted 3D PD-weighted image of the craniocervical junction shows a ruptured alar ligament on the right (grade 3 lesion).

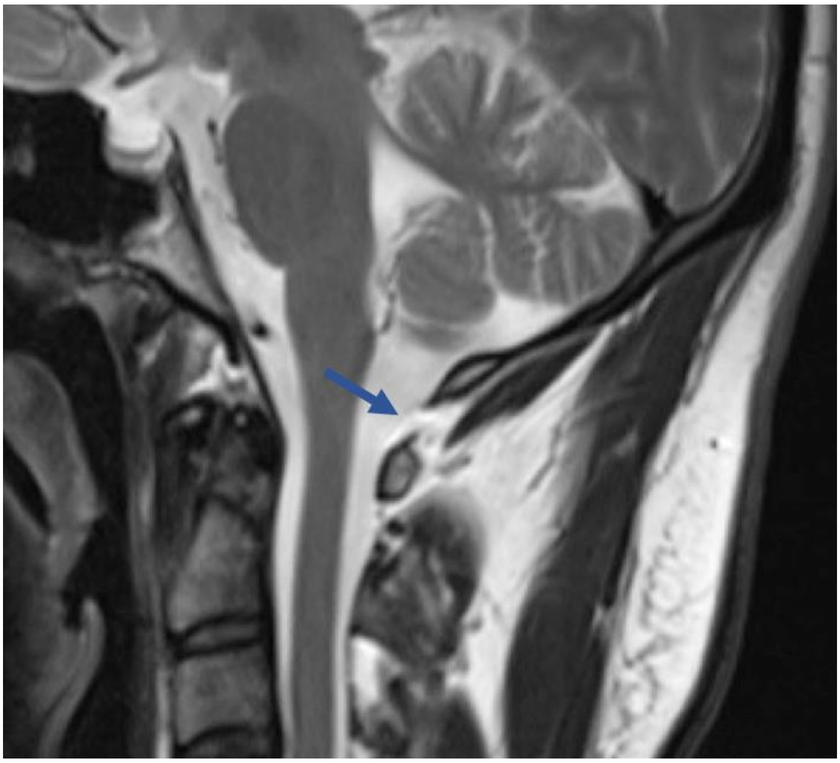


Figure 10: Patient with severe whiplash injury. Sagittal T2-weighted MRI show a complete rupture (grade 3 lesion) of the posterior atlanto-occipital membrane (PAOM). Severe injuries to the tectorial membrane and the PAOM can sometimes also be detected on 'regular' sagittal T2-weighted images as in this case. Still, more subtle lesions (grade 1), and lesions to the transverse and alar ligaments are usually only visible on thin slice 3D-PD-weighted images.

4. Injuries to the intervertebral discs and vertebral endplates

In whiplash injuries, the cervical spine is exposed to severe flexion, extension, and translational forces. These forces may negatively affect the intervertebral disc and vertebral endplates. Long-term degenerative changes of the vertebral endplates and more especially changes in the bone marrow in the lumbar spine are classified in the Modic-classification. Modic-type changes in the endplates of the vertebral bodies are extensively described in the lumbar spine, but less frequent in the cervical spine and theoretically the description "Modic-type changes" is reserved for changes in the lumbar spine. Modic type changes are classified as type I (low T1 and high T2 signal), type II (high T1 and high T2 signal) and type III (low T1 and low T2 signal). These T2-hyperintensities can be seen on STIR and T2-Dixon imaging sequences, whereas STIR sequences being more reliable due to its more robust fat suppression and higher sensitivity. It is postulated that Modic-like changes are more likely to develop in patients with cervical whiplash injuries caused by vehicle collision forces than in healthy individuals.

As described by Pettersson in 1997, disc pathology was described as a consequence of whiplash injury and may be a contributing factor in the development of chronic symptoms. However, clinical significance appeared to be limited due to the high proportion of false-positive results. [31] Furthermore, post-traumatic disc changes were described as avulsion of the disc from the vertebral endplate and tears of the anterior annulus fibrosus, resembling focal T2-hyperintensity in the anterior disc. [32]

Recent studies have not shown a statistically significant association between whiplash trauma and progressive Modic type changes in a 10-year prospective follow-up. Modic-type changes occurred with a similar frequency in comparison to control subjects. [33,34] In the acute stage, post-traumatic T2-hyperintensities in the vertebral bodies and endplates are difficult to distinguish from age-related and degenerative changes. However, it should be noted that in the setting of a high-impact trauma to the cervical spinal, bone marrow oedema should raise suspicion. It should first be attributed to bone abnormalities of vertebral bodies, occult fractures, or bone contusions until evidence to the contrary.

5. Injuries to the spinal muscles

Post-traumatic changes in the (para-)spinal soft tissues can also be seen in whiplash injuries, depending on the severity of the injury. In acute post-traumatic MR-imaging, there are diffuse T2-hyperintensities in the soft tissues, resembling reactive oedema due to (micro-)rupture of fibres. Full-thickness rupture of the para-spinal muscles is characterized by retraction and hazy delineation of the muscle ends. In complete rupture, there is disproportionate T2-hyperintensity compared to the adjacent soft tissues. A focal intramuscular heterogenous mass can also be seen in the para-spinal muscles, which resembles an intramuscular hematoma. In patients with whiplash-associated disorders, fatty infiltration of the paraspinal muscles (e.g., m. multifidus) can be seen. It has been shown that there are greater levels of multifidus fat infiltration in persistent severe pain-related disability after a whiplash injury. Also, rapid and progressive degeneration of the multifidus muscle is postulated as a consequence of whiplash injury. [35-38] We believe that in patients with WAD, these fatty infiltrates are secondary and the result of antalgic postural changes, rather than direct traumatic changes.

On plain film swelling of the prevertebral soft tissues can be seen, which is a sign of acute cervical spinal trauma. This can resemble a focal disruption of the anterior longitudinal ligament or may indicate a sprain of the longus colli or longus capiti muscle. [39] On functional images of the cervical spine, a kyphotic angle of the cervical shouldn't be directly attributed to soft-tissue injury, as shown by Ronnen et. al. This can be attributed to a compensating mechanism of hypermobility, above the level at which hypomobility occurs due to muscle spasm. [40]

6. Injuries of the osseous structures

The imaging modality of choice in the assessment of fractures in the craniocervical junction is computed tomography (CT). Plain film X-ray will also detect severe fractures but is less preferred due to its lower sensitivity. Radiological detection of (avulsion) fractures in the CCJ plays a fundamental role in patient outcomes.

6.1 Occipital condylar fractures

Occipital condylar fractures are rare fractures that can be seen in high-impact trauma. Detection of these fractures is important, as this may require surgical intervention and can cause instability of the craniocervical junction. It should be carefully looked at on CT, preferably in the coronal plane. There may be subtle changes to the occipital condyles that can be missed on axial or sagittal images. Most commonly the Anderson and Montesano classification[22,41] is used to describe occipital condylar fractures:

Type I: *Impacted type occipital condyle fracture with comminution. Ipsilateral alar ligament may be compromised. Stable due to intact contralateral alar ligament and tectorial membrane.*
Type II*: Linear skull base fracture, extending from the occipital bone to the occipital condyle. Stable fracture due to intact alar ligaments and tectorial membrane.*
Type III*: Alar ligament avulsion displaced toward the odontoid process due to rotational trauma. Potentially unstable (►* ***Fig.*** *7).*

A new simple classification is proposed by Muller et. al. al in 2012, which takes the possible association with atlanto-occipital-dissociation (AOD) into account. [42]

Type I*: Unilateral occipital condylar fracture without atlanto-occipital-dissociation (AOD). Stable.*
Type II: *Bilateral occipital condylar fracture without atlanto-occipital-dissociation (AOD). Stable.*
Type III*: Unilateral or bilateral occipital condylar fracture with atlanto-occipital-dissociation (AOD). Requires surgical intervention.*

6.2 Atlas fractures

In high-energy trauma, fractures may also occur to the atlas due to severe hyperextension or extreme axial forces. Because of its ring-shaped morphology, atlas fractures most frequently occur in two or more places (arch, lateral mass or transverse process). Isolated fractures can also occur. A classification was made by Gehweiler et. al. [43,44] On CT, it is challenging to report a rupture of the transverse ligament. However, an increased atlanto-dental interval (>3mm) combined with an increased offset of the lateral mass (>3mm), is specific for a disruption of the transverse ligament. [45] A Gehweiler type V fracture always needs to be complemented with CT-angiography as these types of fractures may cause dissection of the vertebral artery.

Type I*: Fractures of the anterior arch.*
Type II: *Fractures of the posterior arch, most commonly bilateral.*
Type III*: Jefferson fracture. Fracture of the anterior and posterior arch.*
- ***Type IIIa****: Intact transverse ligament.*
- ***Type IIIb****: Disrupted transverse ligament complex, associated bony avulsion of the medial tubercle*

Type IV*: Fractures of the lateral mass*
Type V*: Isolated fracture of the C1 transverse process.*

6.3 Axis fractures: odontoid process

An odontoid process fracture is the most frequent posttraumatic bone lesion of the axis, occurring in both (young) adults and elderly patients. It should be evaluated thoroughly, as these lesions may be unstable and cause spinal cord injuries. CT is the imaging modality of choice when an axis fracture is suspected. CT findings can be classified according to the Anderson & D'Alonzo classification. [46] Grauer et. al. then further suggested three different subtypes of type II fractures, which provides a more objective approach to management strategies.[47,48]

Type I*: Fracture of the odontoid peg, above the level of the transverse ligament.*
Type IIa*: Transverse fracture at the base without displacement*
Type IIb*: Antero-superior to postero-inferior and/or >1mm displacement.*
Type IIc*: Antero-inferior to postero-superior or > comminution.*
Type III*: Fracture through the odontoid process and into the lateral masses of C2*

7. Discussion

The term "whiplash" was used to describe the movement the head makes in a motor vehicle accident, causing injuries to the cervical spine and associated soft tissues. In whiplash injuries, the cervical spine is exposed to severe flexion, extension, and translational forces. This trauma mechanism may cause injuries to the craniocervical junction (CCJ). In this radiological review we depict the most frequent lesions caused by whiplash-type injuries. CT is the modality of choice in ruling out acute osseous lesions. Fractures in whiplash-injuries are less frequent than ligamentous injuries. Injuries to the ligaments of the craniocervical junction are assessed by MRI, as it provides a superior contrast resolution (►**Figs. 7, 8, 9**). Proton-density 3D turbo/fast spin echo with variable flip-angle distribution should be utilized in assessing the craniocervical junction (3D TSE PD, SPACE/CUBE/VISTA). [16] Ligamentous lesions can be graded on 3D PD-weighted imaging of the CCJ. One should keep in mind that PD-hyperintensities within the ligament can also be attributed to age related changes, especially in the transverse ligament. [17] Most frequently, whiplash associated ligamentous lesions are grade 1 or 2 lesions. Grade 3 lesions are rarer. These complete ruptures, especially of the tectorial membrane and the PAOM can also be detected on 'regular' sagittal T2-weighted images **(**►**Fig. 10**). Fractures are rare and typically not seen in whiplash. This is why several studies postulate that ligamentous lesions are key in the pathophysiology of whiplash associated disorders (WAD). Krakenes et. al. showed a higher Neck Disability Index in patients with whiplash injuries compared with a control group. In the whiplash group, NDI score increased with increasing MRI grading for the alar ligaments (p=0.002). They showed a similar result for transverse ligament injury, but not for the membranes of the CCJ. [49] Furthermore, Chen et. al. reported that in 15.7% of the patients, whiplash ligament injury was shown to be the reason of long-term neck pain and headaches. [50] Possible transverse ligament involvement was also shown by Ulbrich et. al. as they saw a higher STIR signal in patients with whiplash compared to a control group (p = 0.007). [51] A recent study conducted by Uhrenholt et. al. reported a higher prevalence of alar and transverse ligament signal changes and reduced disc height among chronic whiplash cases, however lacked statistical significance. [52] Combined, these results add to the hypothesis that ligamentous injuries play an important role in the pathophysiology of WAD. In contrast, several papers haven't found any association between ligamentous lesions of the CCJ and WAD. Dullerud et. al. weren't able to show significant differences in ligaments of the CCJ in patients with whiplash injuries compared to a control group. [53] Another study by Myran et. al. questioned the diagnostic value of high intensity signal within the ligament as they could not attributed these changes to the trauma itself.[54] Studies that failed to confirm the role of ligamentous injuries in WAD, and yielded non-significant findings, may have been subject to insufficient statistical power due to study design and factors as low sample size and/or selection bias. We firmly believe that WAD is indeed most frequently caused by ligamentous injuries of the CCJ, mainly lesions to the transverse and alar ligaments. Therefore, sagittal 3D PD-weighted imaging sequences should be routinely included in MRI of patients with whiplash injuries.

8. Conclusion

Whiplash-type injuries are one of the most common traumatic lesions of the cervical spine, more specifically of the craniocervical junction. Although CT has been widely used to rule out fractures and dislocations, as some of these lesions may require surgical intervention, the vast majority of these patients does not have an osseous lesion. MRI with specific 3D PD-imaging of the CCJ is a must in evaluating whiplash-injured patients since injury to the ligaments of the CCJ, especially the transverse and alar ligaments play a major role in the pathophysiology of this trauma. In interpreting imaging findings, one must be aware of the changes in these ligaments with age, but in most cases, WAD is seen in young patients in whom ligaments normally are grade 0. Any grade 1, 2 or 3 CCJ ligamentous lesion in a young patient with WAD should be considered abnormal and be attributed to trauma, until proven otherwise.

9. Disclosures

The authors have no conflicts of interest to declare.

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