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Variations in the atlantoaxial joint detected by computed tomography in control patients

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ABSTRACT

Introduction: Whiplash injuries can lead to prolonged, widespread symptoms known as whiplash-associated disorders (WAD), which are suggested to be caused by instability of the C1-C2 junction. However, there is limited published data on the typical extent of rotations and transitions of facets in the C1-C2 region.
Methods: Here we conducted a study examining the rotation between the C1 and C2 vertebrae, the lateral atlantodental interval, and C1-C2 facet joint alignment in 100 patients with no prior neck trauma or prolonged neck complaints using computed tomography.
Results: Rotations up to 11° between C1 and C2 were observed in 84 % of the patients. Dens asymmetry of up to 1.9 mm was observed in 81 % of the patients. The facets were misaligned up to 5 mm in 42 % of the patients. There was no statistically significant correlation between the rotation of C1 and asymmetry of dens. As expected, head rotation in the head support correlated to the rotation between C1 and C2 and C1-C2 rotation correlated to the misalignment of facets.
Conclusion: The results of this study show that in a population without neck symptoms, almost all patients (98 %) exhibit rotation between C1 and C2, dens asymmetry or facet misalignment.
Implications for practice: These radiological findings represent normal anatomical variations rather than imply craniocervical junction instability.

Introduction

Whiplash injuries resulting from rear-end collisions involving motor vehicles are the most common causes of neck injuries. In some instances, these injuries can lead to prolonged, widespread symptoms referred to as whiplash-associated disorders (WAD). These symptoms extend beyond neck pain and stiffness, encompassing a range of issues such as memory problems, depression, sleeping difficulties, dizziness, poor balance, vision problems, nausea, headaches, photophobia, and hyperacusis.[1–3] The underlying pathophysiology of these problems remains poorly understood. Strain-induced injuries to muscles, ligaments, and joints are suspected to contribute to these symptoms.

Computed tomography of the cervical spine is the primary imaging modality after cervical spine trauma as it can detect fractures and dislocations of the bone structures. If the patient has neurological or prolonged symptoms or ligamentous injury is suspected, MRI imaging is indicated. Among WAD grades I–III, as classified by the Quebec Task Force on Clinical Classification of WAD,[3] patients' MRI-imaging may reveal muscle strains, tears or hematomas or perimuscular fluid, but these findings are extremely rare.[4]

In severe cases classified as WAD grade IV, radiological findings should reveal fractures and/or (sub)luxations evident in radiologic imaging. For milder injuries falling under WAD grades I-III, the findings are nonspecific and may include vertebral body and facet contusions, intervertebral disk herniations, ligament and muscle strains and tears, and perimuscular fluid. However, there is poor

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interobserver reliability for these changes, and they are also frequently found in healthy control patients.[4]

It has been suggested that persistent symptoms following a whiplash injury, particularly neck pain, result from injuries to the alar and transverse ligaments,[5] which play a significant role in stabilizing the craniocervical junction. These injuries were initially proposed to be evidenced by signal changes in these ligaments on MRI scans. However, this hypothesis has been subsequently refuted, as several studies have shown that MRI signal changes in the alar and transverse ligament were not associated with WAD.[6]

Recent focus on persistent WAD-associated symptoms has shifted from the alar ligaments to misalignments of the C1 and C2 vertebrae. However, beyond atlanto-axial subluxation, there is limited data on the typical range of rotation and facet misalignment in the C1-C2 region. To address this gap, we conducted a study examining the rotation between the C1 and C2 vertebrae, the lateral atlantodental interval, and C1-C2 facet joint alignment in 100 patients with no prior neck trauma or prolonged neck complaints using computed tomography (CT).

Methods

We retrospectively screened 124 patients above 18-years old, who underwent neck and head, or aorta/neck and head computed tomography angiography (CTA) between September 2022 and January 2023. The indication for the CTA was acute symptoms of brain ischemia, transient ischemic attack, vertigo, chest pain or suspicion of carotid stenosis. The exclusion criteria for the study were previous head/neck/spine surgery, previous trauma of head/neck/spine region, rheumatoid arthritis, chronic neck pain, severe hemiplegia, unconsciousness, and gross abnormalities of upper cervical region.

A GE HealthCare Revolution CT scanner was used with the following acquisition parameters: 120 kVp, 80–460 mA with the SmartmA dose optimization technique, a noise index of 12.0, and the HD standard reconstruction algorithm. These settings yielded 0.625-mm-thick CT images of the atlantoaxial junction, which were analyzed using a preset bone window with a window level of 800 HU and a window width of 2000 HU. The analysis was performed by a neuroradiologist (KB) with 9 years of experience.

Using a picture archiving and communication system (PACS) workstation, we obtained a total of 10 measurements on each patient including the following:

1. Head rotation relative to centrally oriented head support.
2. Position of the dens relative to the C1 lateral mass (asymmetry of dens; Fig. 1a).
3. Rotation of C2 corpus relative to C1 (Fig. 1b)
4. Rotation of the dens relative to C1 (Fig. 1c).
5. Anteroposterior measurement of C1 and C2 lateral facet lengths.
6. C2 lateral facet transition relative to C1 lateral facet (Fig. 1d).

The degree of rotation was quantitated on axial CT image by comparing the anteroposterior axes of the head (line congruent with the falx and nasal septum), atlas (line connecting the anterior and posterior tubercle), dens (line connecting the middle point of ventral cortex to the middle point of dorsal cortex) and axis (line connecting the middle point of the base of odontoid process to the spinous process). Negative values indicate counterclockwise (CCW) rotation, while positive values indicate clockwise (CW) rotation.

The asymmetric localization of dens corresponding to C1 lateral masses was evaluated on the mid-coronal plane of atlanto-axial joint measuring both right and left lateral atlantoaxial interval (distance between the medial-most aspect of the lateral mass of the atlas to the lateral aspect of the dens). Transition to the left was marked as a negative value, and to the right as a positive value.

The transition of the C2 lateral articular surface was measured on sagittal plane by comparing the position of C1 and C2 lateral facets to each other at the middle part of facet articulation. Anterior C2 facet transition corresponding to the C1 facet was marked as positive and posterior transition as negative.

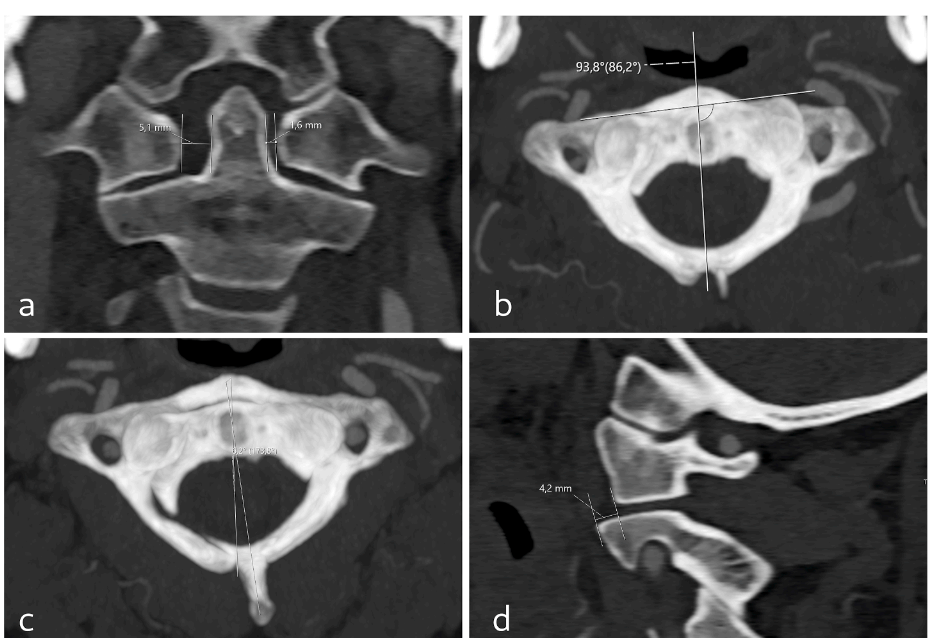

Figure 1. Computed tomography demonstrating lateral asymmetry of the dens (a), rotation between the C1 and C2 vertebrae (b), rotation between the dens and the C1 vertebra (c), and transition between the C1 and C2 facets (d).

Results

Of the 124 study patients screened, 24 were excluded and 100 were selected for radiological analysis. Forty-eight of the patients were women and 52 men. The patients were 27–89 years of age. The mean age was 68 for women and 65 for men and the mean age for all patients was 66.

There was no statistically significant difference in dens asymmetry between the left and right sides (Fig. 2a), the CW or CCW rotation of the C2 vertebra relative to C1 (Fig. 2b), the CW or CCW rotation of the dens relative to C1, or the CW or CCW rotation of the head relative to the head support. The mean distance of the dens from the midpoint was 0.5 mm.

There was a strong correlation between the rotation of dens relative to C1 corpus and the rotation of C2 corpus relative to C1 corpus (cor $= 0.87$, CI [0.81, 0.91], $p < 2.2e\text{-}16$ Pearson's product-moment correlation). The mean rotation of C2 corpus relative to C1 was 3.0° and the mean rotation of dens relative to C1 corpus was 2.7°. There was no statistically significant difference between the rotation of the dens relative to the C1 corpus and the rotation of the C2 corpus relative to the C1 corpus (CI [−0.64–1.49], $p = 0.43$). There were three patients with CCW rotation of dens relative to C1 corpus but CW rotation of C2 corpus relative to C1 corpus.

There was no correlation between the rotation of the C2 vertebra relative to the C1 vertebra and the asymmetry of the dens (cor $= -0.05$, CI [−0.24, 0.15], $p = 0.64$, Pearson's product-moment correlation). Rotation between C1 and C2 vertebrae correlated with head rotation relative to head support (cor −0.37, CI [−0.53, −0.19], $p = 0.0002$), though 15 patients showed rotations to the opposite sides.

The C2 facet was longer than the C1 facet in 77 patients (CI [−1.58, −0.92], $p = 1.59e\text{-}11$; CI [−1.16, −0.66], $p = 7.67e\text{-}11$ on the left and right side, respectively). The mean lengths of the C1 and C2 facets were 16.7 mm and 17.8 mm respectively.

There was no statistically significant difference between the facet transitions on the left and right sides. The mean transitions on the left and right sides were 0.38 mm and 0.76 mm, respectively (CI [−0.54, 0.10], $p = 0.17$). Usually, the C2 facet was located anterior to the C1 facet (Fig. 3a). There was a slight but statistically significant negative correlation between the facet transitions on different sides (cor $= -0.23$, CI [−0.41, −0.04], $p = 0.018$, Pearson's product-moment correlation; Fig. 3b). The total summarized rotation between C1 and C2 correlated with the degree of facet transition (cor $= 0.79$, CI [0.70, 0.85], $p < 2.2e\text{-}16$).

Discussion

Craniocervical instability has been suggested as a cause of prolonged symptoms following whiplash injury and has also been associated with postural orthostatic tachycardia syndrome and chronic fatigue syndrome.[7] Aside from atlantoaxial subluxation, however, there is very little evidence regarding the relationship between the C1 and C2 vertebrae in both normal patients and pathological conditions, and no pathological threshold values exist. Functional MRI (fMRI) was introduced in 1997 as a tool to detect instability of the craniocervical junction.[8] The observed instability was suggested to be caused by injuries to the alar ligaments visible in the same study and they were indication to operative treatment, i.e. stabilization surgery at the C0-C1-C2 level.[9,10] These operations were performed to a significant number of patients not only in Germany, but also in Scandinavia.[11–13] However, it was later established that the suggested pathological changes in the alar ligaments were based on a misinterpretation of MRI findings, and that surgical stabilization of the cervical spine was not indicated based on the fMRI results.[14]

Thereafter the recent focus has shifted to the rotation between the C1-C2 vertebrae, the localization of the dens in relation to the C1 vertebra, and the alignment of C1 and C2 facet joints. These

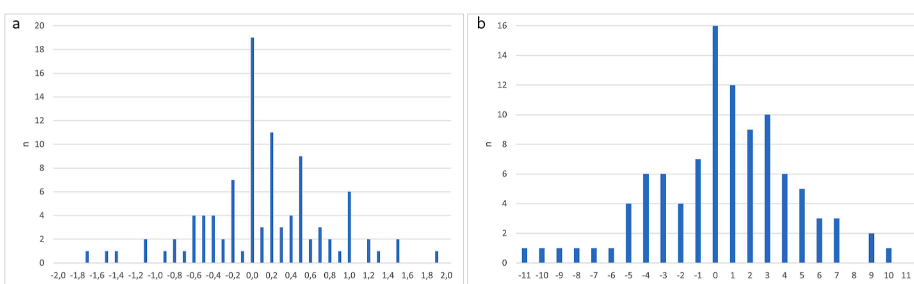

Figure 2. Asymmetry of the dens (in millimeters) (a) and rotation between the C1 and C2 vertebrae (b).

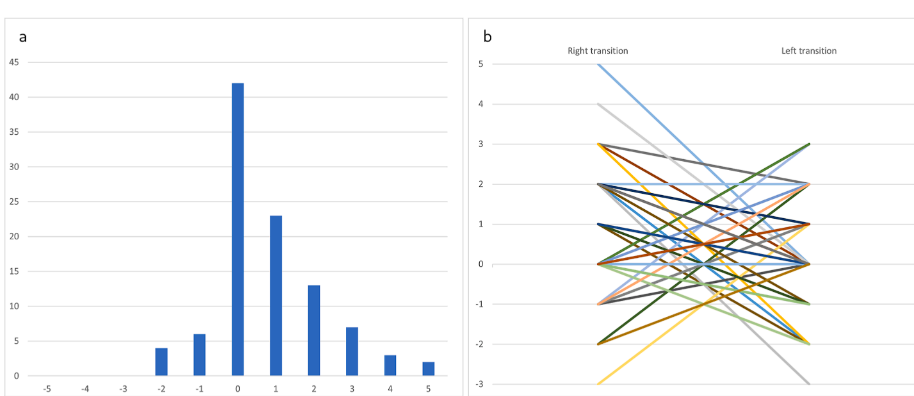

Figure 3. Anterior and posterior transitions of the C1 and C2 facets (a) and the correlation between left and right facet transitions (b).

findings have been mistakenly labeled as dislocation, (sub)luxation, relative luxation and retroposition. These misinterpreted findings have been regarded as signs of craniocervical joint instability, leading to their classification as post-traumatic changes and making them eligible for compensation under insurance terms and conditions. Although no pathological threshold values exist for these changes, they have led to surgical fusion of the C1-C2 vertebrae.[15,16] Therefore, we examined the types of misalignments or asymmetries that can be observed in patients with no history of neck trauma or other neck complaints. As expected, we observed no differences between CW and CCW rotations of the C2 corpus or the dens relative to C1, left or right asymmetry of dens, or in the anteroposterior transitions of the left and right facets. Detecting such differences would have indicated a systematic error in the imaging process. Rotations of up to 11° between the C1 and C2 vertebrae were observed in 84 % of study patients, even though their heads were carefully positioned in the midline during the imaging procedure. As expected, there was a strong correlation between the rotation of the dens relative to the C1 corpus and the rotation of the C2 corpus relative to the C1 corpus. However, the measured values were not identical, with three patients exhibiting rotations to opposite sides, indicating anatomical variation in the C2 vertebra. This variation results in different values when measuring rotation from the C2 corpus and the dens.

As previously shown[17] the rotation between C1 and C2 does not correlate with the asymmetry of dens. We observed asymmetry ranging from 0.1 mm to 1.9 mm in 81 % of the study patients. The maximal asymmetry presented here was considerably less than in a previous study, where asymmetry up to 5 mm were observed.[18]

As expected, rotation of the head in the apparatus caused rotation of C1 relative to C2 with a statistically significant correlation between the two. However, observed rotations were not equal, as in 15 patients rotation in the apparatus and rotation between C1 and C2 was to opposite sides, indicating that anatomical variations influence measured values.

There was a statistically significant negative correlation between the widths of facet transitions on different sides and the sum of left and right facet transitions correlated with the C1-C2 rotation. However, also this pattern was not consistent for every patient, as three patients had anterior facet transitions on both sides. Notably, there were no patients with posterior facet transitions on both sides. As an anatomical detail, the C2 facet was usually longer than the C1 facet.

The clinical relevance and impact on practice lie in demonstrating anatomical variations of the atlantoaxial joint in patients without neck complaints, providing valuable context for interpreting radiological findings in suspected craniocervical instability, surgical candidates, and whiplash patients.

The limitations of the present study are that, since this was a retrospective study, we do not have complete information on the patients' actual positioning, even though they were intended to be positioned straight. Second, although we screened the patients for previous neck injuries and complaints, they may have had neck injuries that were treated elsewhere.

Conclusions

Head rotation causes rotation between C1 and C2, but the correlation between head rotation and C1-C2 rotation is not absolute. Measuring rotation of C2 relative to C1 from dens or C2 corpus produces slightly different values. Similarly, the anterior and posterior transitions of the facets correlated with each other, but this correlation was also not absolute. Almost all the study patients demonstrated some kind of transition of facets, asymmetry of dens or rotation between the C1 and C2 vertebrae. Out of the 100 patients measured, the dens was centrally positioned with no rotation between the C1 and C2 vertebrae and the facets aligned in only two patients. These observed changes in the positioning of the C1 and C2 vertebrae are normal and not indicative of whiplash injury, nor do they require surgery.

Ethics approval and consent to participate

All procedures were performed in compliance with relevant laws and institutional guidelines and have been approved by the Wellbeing services county of Pirkanmaa. Ethical approval was not sought because permission for this study was obtained from the Wellbeing Services of Pirkanmaa (R23570; § 91/2023).

Informed consent for patient information to be published in this article was not obtained because the Act on the Secondary Use of Health and Social Data in Finland (552/2019) permits the use of data created during health and social service sector activities for purposes other than the original reason for which it was collected. In such cases, patient informed consent is not required.

Availability of data

Data required for this study may be made available by the author(s) upon reasonable request.

Author contributions

HP, Conceptualization, Formal analysis, Writing - Original Draft, Writing - Review & Editing, Visualization; KB, Methodology, Validation, Investigation, Resources, Data Curation, Visualization; RO, Conceptualization, Validation, Formal analysis, Investigation, Writing - Review & Editing; JH, Conceptualization, Methodology, Validation, Formal analysis, Data Curation, Writing - Review & Editing, Visualization, Supervision, Project administration, Funding acquisition.

Availability of data

Data required for this study may be made available by the author(s) upon reasonable request.

Declaration of Generative AI and AI-assisted technologies in the writing process

Not applicable.

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Conflict of interest statement

JH reports a relationship with Lundbeck, Amgen, Finva, Fennia, If, Finnish Motor Insurers' Centre, LähiTapiola, OP Pohjola, Pohjantähti, Patient Insurance Centre, Accident Appeal Board, State Treasury that includes: consulting or advisory, paid expert testimony, and speaking and lecture fees. RO reports a relationship with Finnish Parkinson Foundation, State Research Funding, The Finnish Medical Foundation sr., Finnish Movement Disorders Association, Orion, Abbvie-Allergan, Ipsen, Orion, Movement disorder division of the Finnish Neurological Society that includes: board membership, funding grants, speaking and lecture fees, and travel reimbursement. The other authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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