Original Article

# Imaging Evaluation of Suspected Craniovertebral Junction Anomalies Using CT, MRI and CT Vertebral Angiography

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## Abstract

**Background:** Craniovertebral junction (CVJ) anomalies represent a heterogeneous group of structural deformities involving the occiput, atlas, and axis with their supporting ligamentous apparatus. These anomalies carry significant neurosurgical implications and are encountered more frequently in the Indian subcontinent than elsewhere in the world. The objective is to evaluate the incidence of congenital CVJ anomalies across age groups, assess sex prevalence, characterise radiological abnormalities on CT and MRI, and document the course of the vertebral artery in order to inform surgical planning. **Material and Methods:** A hospital-based descriptive study was conducted from January 2018 to June 2019. Thirty patients with confirmed congenital CVJ anomalies underwent CT and/or MRI evaluation. Standard craniometric measurements — McRae's line, Chamberlain's line, McGregor's line, bimastoid line, digastric line, Wackenheim's clivus canal line, clivus canal angle, and Welcher's basal angle — were recorded. CT angiography was performed where vertebral artery anomalies were suspected. **Results:** CVJ anomalies were distributed across all age groups, with the 31–40 year cohort most commonly affected (23.3%). Males constituted 76.7% of cases ($p = 0.01$). Bony anomalies predominated (97%), with basilar invagination being the most frequent diagnosis in 80% of patients. All six standard craniometric lines were abnormal in 80% of cases. Arnold-Chiari malformation was the principal soft tissue anomaly (6%). Abnormal vertebral artery course was identified in 30% of cases, predominantly involving the V3 segment. **Conclusion:** Congenital bony anomalies, particularly basilar invagination, dominate the CVJ anomaly spectrum with a significant male preponderance. Pre-operative CT angiographic evaluation of the vertebral artery is essential, given its aberrant course in nearly one-third of patients. CT and MRI together constitute the gold standard for diagnosis and surgical planning.

**Keywords:** Craniovertebral junction anomalies; basilar invagination; Arnold-Chiari malformation; craniometric measurements; vertebral artery; CT; MRI; occipitalisation of atlas.

**Received: 01 July 2026** **Revised: 19 July 2026** **Accepted: 01 August 2026** **Published: 13 August 2026**

## Introduction

The craniovertebral junction (CVJ) constitutes the most anatomically complex and biomechanically dynamic region of the axial skeleton. Serving as the transitional zone between the cranium and the cervical spine, it encompasses the occiput, atlas (C1), axis (C2), and their intricate network of ligamentous stabilisers. The CVJ houses critical neurovascular structures including the lower brainstem, cervicomedullary junction, upper cervical spinal cord, cranial nerves IX–XII, and the vertebral arteries as they traverse towards the foramen magnum. Disruption of the delicate balance within this region — whether by congenital malformation, acquired disease, or trauma — can produce a spectrum of neurological deficits ranging from subtle sensorimotor disturbances to life-threatening myelopathy.

Congenital CVJ anomalies arise from failures of segmentation, assimilation, or ossification during embryological development. Epidemiological data consistently demonstrate a higher prevalence of these anomalies in the Indian subcontinent compared to Western populations, with a particularly elevated incidence reported from the northern Indian states of Bihar, Uttar Pradesh, Rajasthan, and Gujarat. Contributing factors include consanguinity, nutritional deficiencies, and genetic predisposition, though the exact aetiopathogenesis remains incompletely understood.[1,2]

Historically, CVJ anomalies were diagnosed late owing to their insidious clinical course and the limitations of plain radiography. The advent of high-resolution computed tomography (CT) with multiplanar reconstruction and magnetic resonance imaging (MRI) has revolutionised both diagnosis and pre-operative planning. CT delineates the osseous architecture and permits precise craniometric measurements, while MRI provides unparalleled assessment of the cervicomedullary junction, CSF

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DOI:
10.21276/amit.2026.v13.i2.936

**How to cite this article:** Thaiyalnayaki S, Karthick M, Balamurugan PP. Imaging Evaluation Of Suspected Craniovertebral Junction Anomalies Using Ct, Mri And Ct Vertebral Angiography. Acta Med Int. 2026;13(2):1670-1675.

flow dynamics, and soft tissue pathology.[3,4] CT angiography has additionally proven indispensable for characterising vertebral artery anomalies that frequently coexist with bony malformations and pose significant intraoperative risk if unrecognised.

Despite the clinical importance of CVJ anomalies, large descriptive studies from tertiary care centres in India remain relatively scarce. The present study was therefore undertaken to systematically characterise the radiological profile of congenital CVJ anomalies at a South Indian tertiary institution, with particular emphasis on craniometric analysis, anomaly type and distribution, sex and age prevalence, and vertebral artery course.

The specific objectives of this study were: (1) to determine the incidence and distribution of various congenital CVJ anomalies across age and sex groups; (2) to evaluate the osseous, cervicomedullary, CSF, and vascular components of CVJ anomalies using CT and MRI; (3) to assess the role of standardised craniometric measurements in radiological diagnosis; and (4) to document the prevalence and patterns of vertebral artery course variation, stressing the importance of pre-operative angiographic evaluation.

## Materials and Methods

This hospital-based cross-sectional descriptive study was conducted in the Department of Radiology, Government Coimbatore Medical College Hospital, Coimbatore, Tamil Nadu, India, from January 2018 to June 2019. The study was performed in collaboration with the Departments of Neuromedicine and Neurosurgery.

All patients of any age and sex presenting to the neurology and neurosurgery services with clinical features suggestive of CVJ pathology were considered for inclusion. A total of 30 patients with radiologically confirmed congenital CVJ anomalies constituted the study cohort. Acquired causes of CVJ pathology — including Paget's disease, rheumatoid arthritis, osteomalacia, achondroplasia, Down syndrome, and traumatic dislocations — were excluded to maintain homogeneity of the congenital study group. Written informed consent was obtained from all patients and/or their guardians prior to imaging. Institutional ethical clearance was obtained in accordance with prevailing guidelines.

All patients underwent thin-section CT of the CVJ with multiplanar reformats in sagittal, coronal, and axial planes. MRI was performed using T1-weighted and T2-weighted sequences in sagittal and coronal planes. For CT angiography, iohexol contrast agent was administered intravenously following a test dose and informed consent. CT angiography was performed in patients where vertebral artery anomalies were clinically suspected or identified on preliminary imaging. All imaging data were analysed on a PACS workstation by experienced radiologists.

Eight standardised craniometric parameters were assessed on CT and MRI. McRae's line (foramen magnum line connecting basion to opisthion) was considered abnormal when the tip of the dens extended above it. Chamberlain's line (posterior hard palate to inferior occiput) was considered abnormal when the dens apex exceeded 3 mm above it. McGregor's line (posterior hard palate to occiput) was taken as abnormal when the dens apex exceeded 5 mm. The bimastoid line was abnormal when the dens tip lay more than 10 mm above the line connecting both mastoid tips. The digastric line was abnormal when the dens extended above the line joining the digastric fossae on both sides. Wackenheim's clivus canal line was abnormal when the dens transected the clivus tangent line. The clivus canal angle (<150° is abnormal for platybasia) and Welcher's basal angle (>143° is positive for platybasia) were additionally recorded.[5,6]

Data were entered into a structured master chart and analysed using standard statistical software. Categorical variables were expressed as frequencies and percentages. The chi-square test was used to assess sex-based differences for each radiological parameter. A p-value of $< 0.05$ was considered statistically significant.

## Results

Thirty patients with congenital CVJ anomalies were evaluated over the 18-month study period. The age ranged from less than 20 years to 70 years. The 31–40 year age group was the most commonly affected cohort (n = 7; 23.3%), followed by the 21–30 year group (n = 6; 20.0%). The remaining patients were distributed relatively equally among the older age decades, with 5 patients each in the 41–50, 51–60, and 61–70 year groups, and 2 patients below the age of 20 years. The anomalies were broadly distributed between younger (< 40 years: 49%) and older (≥ 40 years: 51%) populations, indicating that CVJ anomalies manifest across the entire adult age spectrum [Table 1].

Of 30 patients, 23 were male (76.7%) and 7 were female (23.3%), yielding a male-to-female ratio of approximately 3.3:1. This difference was statistically significant (p = 0.01), confirming a significant male predominance. In all age subgroups, males outnumbered females. However, the distribution of cases by age did not differ significantly between sexes (p = 0.595), indicating that, while males are more frequently affected, the age of presentation was comparable across both sexes.

**Table 1: Age and Sex Distribution of Congenital CVJ Anomalies (n = 30)**

| Age Group (years) | Male (n) | Female (n) | Total (%) |
|---|---|---|---|
| <20 | 2 | 0 | 2 (6.7%) |
| 21–30 | 5 | 1 | 6 (20.0%) |
| 31–40 | 5 | 2 | 7 (23.3%) |
| 41–50 | 3 | 2 | 5 (16.7%) |
| 51–60 | 4 | 1 | 5 (16.7%) |
| 61–70 | 4 | 1 | 5 (16.7%) |
| Total | 23 (76.7%) | 7 (23.3%) | 30 (100%) |

BI = Basilar Invagination

Craniometric analysis was performed in all 30 patients. Abnormal McRae's line (tip of dens above the foramen magnum line) was documented in 24 patients (80%). Similarly, abnormal Chamberlain's line (dens apex > 3 mm above the palato-occipital line), McGregor's line (dens > 5 mm above line), bimastoid line (dens > 10 mm above bimastoid line), digastric line (dens > 21 mm), and Wackenheim's clivus canal line (dens transecting the clivus tangent) were each abnormal in 24 patients (80%), consistently reflecting the high prevalence of basilar invagination in this series. Abnormal clivus canal angle indicative of platybasia (< 143°) was noted in 8 patients (26.7%). In each craniometric parameter, abnormal measurements were predominantly seen in males, with statistically significant p-values of 0.02 for most parameters [Table 2].

**Table 2: Craniometric Measurements and Their Abnormality Rates (n = 30)**

| Craniometric Line / Angle | Abnormal (n) | Normal (n) | % Abnormal |
|---|---|---|---|
| McRae's Line | 24 | 6 | 80% |
| Chamberlain's Line (>3 mm) | 24 | 6 | 80% |
| McGregor's Line (>5 mm) | 24 | 6 | 80% |
| Bimastoid Line (>10 mm) | 24 | 6 | 80% |
| Digastric Line (>21 mm) | 24 | 6 | 80% |
| Wackenheim's Clivus Canal Line | 24 | 6 | 80% |
| Clivus Canal Angle (<143°) | 8 | 22 | 26.7% |

All six standard craniometric lines showed abnormality in 80% of cases; the clivus canal angle was abnormal in 26.7% (indicating platybasia).

Among the 30 patients, 24 had isolated bony anomalies and 4 had multiple co-existing bony anomalies. One patient had an isolated soft tissue anomaly (Arnold-Chiari malformation) and one had a combined bony and soft tissue anomaly (basilar invagination with Arnold-Chiari malformation). Bony anomalies therefore constituted the overwhelming majority of the CVJ pathology identified in this series (97% in total — 94% as isolated and 3% in combination). Basilar invagination was the single most common anomaly, identified as the primary diagnosis in 19 out of 30 patients (63.3%) in isolation, and contributing to combined anomalies in an additional 5 patients, for an overall prevalence of approximately 80% [Table 3].

Occipitalisation of the atlas was identified in 2 cases as an isolated anomaly (one male, one female) and in 3 additional cases in association with basilar invagination (2 males, 1 female). Arnold-Chiari malformation (Type 1) was diagnosed in 2 patients — once in isolation in a male and once combined with basilar invagination. A solitary case of atlanto-axial dislocation was documented in one male patient. Platybasia was seen in one patient in combination with basilar invagination. There was no statistically significant sex-based difference in the overall CT/MRI diagnostic distribution (p = 0.375), except for basilar invagination which showed a definite male predominance.

**Table 3: CT/MRI Diagnoses — Anomaly Distribution by Sex (n = 30)**

| Anomaly | Male (n) | Female (n) | Total (%) |
|---|---|---|---|
| Basilar Invagination (isolated) | 14 | 5 | 19 (63.3%) |
| Occipitalisation of Atlas (isolated) | 1 | 1 | 2 (6.7%) |
| Arnold-Chiari Malformation (isolated) | 1 | 0 | 1 (3.3%) |
| Atlanto-Axial Dislocation (isolated) | 1 | 0 | 1 (3.3%) |
| Platybasia (isolated) | 0 | 0 | 0 (0%) |
| BI + Occipitalisation of Atlas | 2 | 1 | 3 (10.0%) |
| BI + Arnold-Chiari Malformation | 1 | 0 | 1 (3.3%) |
| BI + Platybasia | 1 | 0 | 1 (3.3%) |
| BI + Multiple Anomalies | 1 | 0 | 1 (3.3%) |
| Total | 23 | 7 | 30 (100%) |

BI = Basilar Invagination; ACM = Arnold-Chiari Malformation

**Course of the Vertebral Artery:** CT angiographic evaluation revealed important vascular findings in a significant proportion of patients. Of 30 patients, 13 (43.3%) had a normal vertebral artery course, while 4 patients (13.3%) demonstrated left-dominant and 2 patients (6.7%) right-dominant vertebral artery configurations — considered variant but not abnormal courses. Truly abnormal vertebral artery courses were documented in 9 patients (30.0%). Two distinct patterns of V3 segment anomaly were identified: passage of the V3 segment through the C0-C1 fusion complex (10%) and passage of the V3 segment below the C1 arch and posterior to the occipitalised C1 lateral mass (20%). Abnormal vertebral artery course was predominantly seen in males (approximately 20% of all patients), with statistical significance (p = 0.034). Most cases of vertebral artery anomaly were associated with multiple bony pathologies, particularly occipitalisation of the atlas [Table 4].

**Table 4: Vertebral Artery Course Distribution by Sex (n = 30)**

| Vertebral Artery Course | Male (n) | Female (n) | Total (%) |
|---|---|---|---|
| Normal course | 11 | 2 | 13 (43.3%) |
| Left dominant | 2 | 2 | 4 (13.3%) |

| | | | |
|---|---|---|---|
| Right dominant | 2 | 0 | 2 (6.7%) |
| Variant – through C0-C1 canal (V3) | 2 | 1 | 3 (10.0%) |
| Variant – below C1 arch / posterior occipitalised lateral mass | 5 | 1 | 6 (20.0%) |
| Total abnormal course | ~6 | ~3 | 9 (30.0%) |

Truly abnormal course (V3 variant) was found in 9/30 patients (30%); predominantly male (p = 0.034).

**Other Findings:** Additional imaging findings included cerebellar tonsillar herniation greater than 5 mm in 2 patients (6.7% — one male, one female), supporting the diagnosis of Arnold-Chiari malformation Type 1. An increased atlanto-dens interval exceeding 3 mm was noted in one male patient, indicating atlanto-axial instability. Flattening of the base of skull (indicating platybasia) was seen in one male. The remaining 26 patients (86.7%) showed none of these additional findings. The difference in these ancillary parameters across sexes was not statistically significant (p = 0.736). The comprehensive statistical significance data for all measured parameters are summarised in [Table 5].

**Table 5: Statistical Significance of Key Parameters by Sex**

| Parameter | P-value | Significance |
|---|---|---|
| Sex distribution (male vs female) | 0.01 | Significant (male predominance) |
| Age distribution vs sex | 0.595 | Not significant |
| Chamberlain's Line (>3 mm) vs sex | 0.02 | Significant (male predominance) |
| McGregor's Line (>5 mm) vs sex | 0.02 | Significant (male predominance) |
| McRae's Line (abnormal) vs sex | 0.02 | Significant (male predominance) |
| Bimastoid Line (>10 mm) vs sex | 0.02 | Significant (male predominance) |
| Clivus Canal Angle (<143°) vs sex | 0.01 | Significant (male predominance) |
| Vertebral artery course (abnormal) vs sex | 0.034 | Significant (male predominance) |
| CT/MRI impression vs sex | 0.375 | Not significant (except BI) |
| Other findings vs sex | 0.736 | Not significant |

p < 0.05 = statistically significant; BI = Basilar Invagination


**Figure 1: Case No. 11 — CT sagittal view demonstrating basilar invagination with the dens tip projecting above the foramen magnum line.**

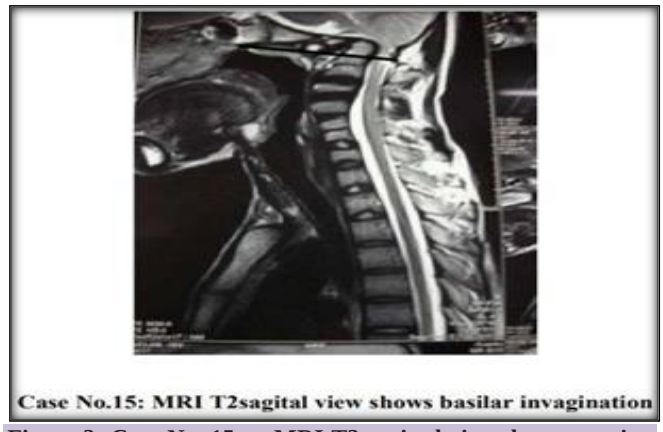


**Figure 2: Case No. 15 — MRI T2 sagittal view demonstrating basilar invagination with upward displacement of the dens and cervicomedullary compression.**

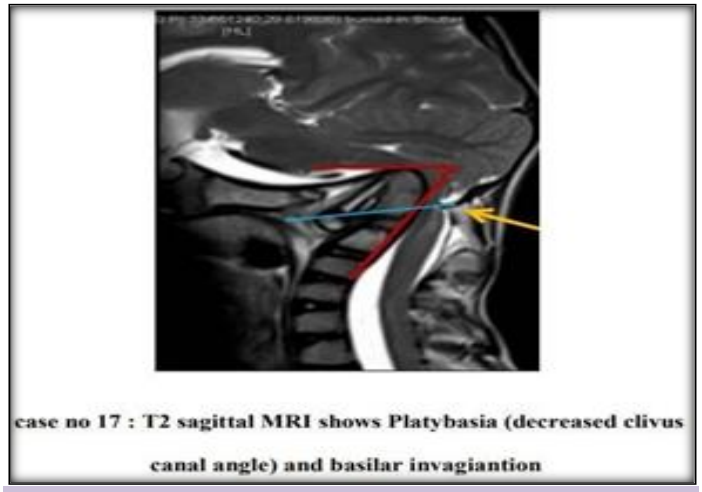


**Figure 3: Case No. 17 — T2 sagittal MRI showing platybasia with reduced clivus canal angle and associated basilar invagination.**

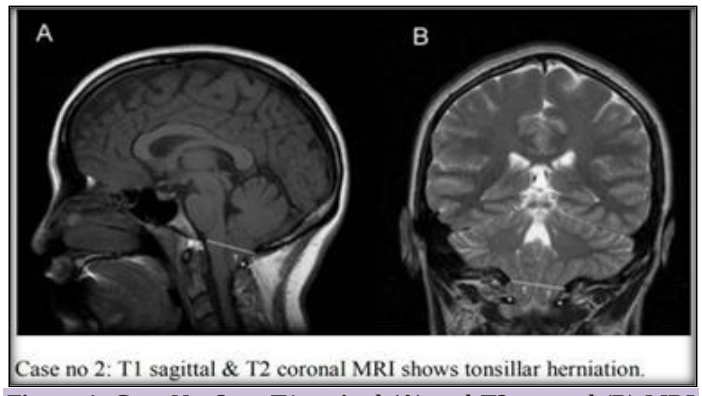


**Figure 4: Case No. 2 — T1 sagittal (A) and T2 coronal (B) MRI demonstrating tonsillar herniation consistent with Arnold-Chiari malformation Type 1.**

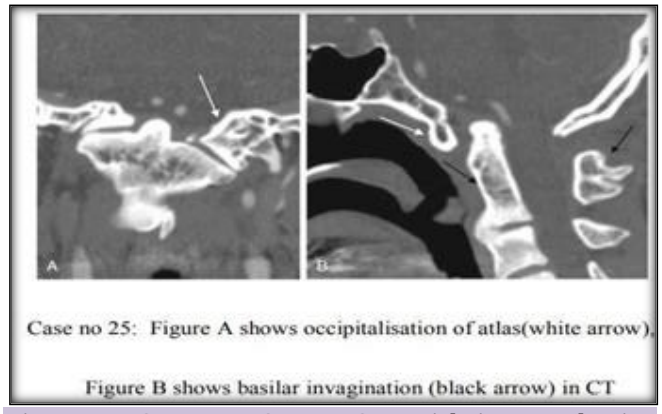


**Figure 5: Case No. 25 — CT axial images showing occipitalisation of atlas (white arrow, Figure A) and associated basilar invagination (black arrow, Figure B).**

## Discussion

The present study provides a systematic radiological characterisation of 30 cases of congenital CVJ anomalies from a tertiary care centre in South India. The findings are largely consistent with established literature while offering several clinically important observations.

Regarding age distribution, CVJ anomalies were identified across all age groups with near-equal representation in patients under and above 40 years of age (49% vs 51%). The 31–40 year cohort constituted the largest single age group (23.3%), followed by the 21–30 year cohort (20.0%). This broad distribution reflects the well-recognised phenomenon whereby congenital bony anomalies remain clinically silent for decades, only becoming symptomatic when superimposed degeneration, minor trauma, or progressive instability erodes the compensatory reserve of the neural elements.[7,8] The finding mirrors results reported by Nath et al. and other Indian series, where CVJ anomalies frequently present in the third and fourth decades.

The striking male predominance (76.7%; p = 0.01) documented in this series has been reported in multiple prior studies. Di Lorenzo et al. and Goel et al. similarly identified male predominance in large surgical CVJ cohorts.[1,7] The biological basis is not entirely clear; however, greater bone mass and the greater propensity of males for subclinical craniometric variations in the Indian population have been proposed as contributing factors. Importantly, while the absolute frequency of anomalies was higher in males, the age at presentation did not differ significantly between sexes (p = 0.595), indicating that sex does not alter the timing of clinical expression.

Basilar invagination emerged as the dominant pathology, present in 80% of cases either in isolation or in combination with other anomalies. This prevalence is consistent with the existing literature from the Indian subcontinent, where basilar invagination rates of 70–85% have been reported in CVJ anomaly series.[9,10] The uniformly abnormal craniometric measurements across all six standard lines in 80% of patients further underscores the diagnostic reliability of this multi-parameter approach. No single craniometric line, taken in isolation, adequately captures the three-dimensional complexity of basilar invagination; the concordant abnormality across McRae's, Chamberlain's, McGregor's, bimastoid, digastric, and Wackenheim's lines provides robust diagnostic confirmation.[5,11]

Occipitalisation of the atlas was identified in 5 patients (16.7%) when combined and isolated cases are counted together, making it the second most common bony anomaly in this series. Its frequent association with basilar invagination is well recognised and has important surgical implications, as the fusion mass alters the biomechanics and limits reduction options.[12] Arnold-Chiari malformation Type 1, characterised by tonsillar herniation greater than 5 mm below the foramen magnum, was the principal soft tissue anomaly (6%), co-existing with basilar invagination in one case. This co-occurrence is mechanistically understandable, as upward displacement of the dens into the foramen magnum reduces available posterior fossa volume and crowds neural structures downward.[13,14]

Perhaps the most surgically relevant finding in this series is the 30% prevalence of abnormal vertebral artery course. Two anatomically distinct V3 segment variants were identified: traversal through the C0-C1 fusion canal (10%) and passage below the C1 arch posterior to the occipitalised lateral mass (20%). Both variants place the vertebral artery at risk during posterior decompressive surgery and occipitocervical fusion, where conventional surgical corridors may transect the vessel if its anomalous course is not recognised pre-operatively.[15,16] This finding strongly supports the routine incorporation of CT angiography — or, where available, MR angiography — into the pre-operative workup of all patients with CVJ anomalies, particularly those with occipitalisation of the atlas. This recommendation aligns with the guidelines proposed by Behari et al. and Wang et al., who demonstrated improved surgical outcomes with pre-operative vascular mapping.[17,18]

CT and MRI together provided complementary and comprehensive information in all cases. CT precisely delineated the osseous anatomy, permitted craniometric measurement, and defined the vertebral artery course via angiography. MRI characterised the degree of cervicomedullary compression, tonsillar herniation, and CSF flow obstruction — information that is not obtainable from CT alone and is essential for planning the extent of decompression.[3,19] The combination of CT and MRI therefore represents the gold standard imaging approach for congenital CVJ anomalies and should be employed in all cases where surgical management is anticipated.

## Conclusion

This descriptive study of 30 patients with congenital craniovertebral junction anomalies confirms that bony malformations, predominantly basilar invagination, account for 97% of cases and exhibit a strong male preponderance (76.7%; p = 0.01). CVJ anomalies manifest across all adult age groups, with the third and fourth decades being the most commonly affected. Standardised craniometric analysis — encompassing McRae's, Chamberlain's, McGregor's, bimastoid, digastric, and Wackenheim's lines — demonstrated a concordant abnormality rate of 80%, affirming their diagnostic reliability as a multi-parameter battery.

Arnold-Chiari malformation was the principal soft tissue

anomaly (6%), frequently co-existing with basilar invagination. A clinically important finding was the 30% prevalence of abnormal V3 vertebral artery course, predominantly in males ($p = 0.034$) and most commonly associated with occipitalisation of the atlas. This underscores the mandatory role of pre-operative CT angiography in all patients being planned for posterior CVJ surgery.

CT provides precise osseous detail and craniometric measurement, while MRI delineates neural compression and soft tissue pathology. Together, they constitute the imaging cornerstone for diagnosis and individualised surgical planning, enabling the neurosurgeon to appreciate the full anatomical complexity of the CVJ and thereby minimise iatrogenic neurovascular injury.

## Financial support and sponsorship

Nil.

## Conflicts of interest

There are no conflicts of interest.

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