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CLINICAL AND NEUROIMAGING FEATURES OF KIMMERLE ANOMALY IN PATIENTS WITH SYMPTOMS OF VERTEBROBASILAR INSUFFICIENCY

Abstract.

Background. Kimmerle anomaly is an osseous variant of the posterior arch of the atlas in which complete or partial ossification of the posterior atlanto-occipital membrane forms an additional bony bridge over the vertebral artery groove. Its clinical relevance remains debated, because the anomaly may be asymptomatic or associated with vertebrobasilar insufficiency.

Methods. A retrospective clinical and neuroimaging study included 82 patients with radiographically confirmed Kimmerle anomaly. All patients underwent neurological examination, symptom stratification, cervical spine radiography, multislice computed tomography, and, when vascular symptoms were present, CT angiography or Doppler ultrasound of the vertebral arteries with functional head-rotation testing. Patients were grouped according to complete or partial bony arch, unilateral or bilateral involvement, and presence or absence of vertebral artery flow disturbance.

Results. Complete Kimmerle anomaly was identified in 31 patients, partial anomaly in 51, unilateral involvement in 49, and bilateral involvement in 33. Vertebral artery flow reduction during testing was detected in 29 patients and was more frequent in complete and bilateral forms. Occipital headache, rotational dizziness, tinnitus, and postural instability were significantly more common among patients with hemodynamically relevant vertebral artery changes.

Conclusion. Symptomatic Kimmerle anomaly should be interpreted as a clinico-radiological entity rather than an incidental skeletal variant. Combined assessment of morphology, vascular dynamics, and symptom pattern improves diagnostic precision and supports personalized management of patients with vertebrobasilar insufficiency syndrome.

Keywords: Kimmerle anomaly, ponticulus posticus, arcuate foramen, atlas, vertebral artery, vertebrobasilar insufficiency, occipital headache, dizziness, multislice computed tomography, CT angiography, Doppler ultrasound, cervicogenic pain.

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КЛИНИКО-НЕЙРОВИЗУАЛИЗАЦИОННЫЕ ОСОБЕННОСТИ АНОМАЛИИ КИММЕРЛИ У ПАЦИЕНТОВ С СИМПТОМАМИ ВЕРТЕБРОБАЗИЛЯРНОЙ НЕДОСТАТОЧНОСТИ

Аннотация.

Введение. Аномалия Киммерли представляет собой костный вариант строения задней дуги атланта, при котором полная или частичная оссификация задней атланто-затылочной мембраны формирует дополнительную костную перемычку над бороздой позвоночной артерии. Клиническая значимость данной аномалии остаётся предметом обсуждения,

поскольку она может быть бессимптомной находкой либо сопровождаться признаками вертебробазилярной недостаточности.

Методы. В ретроспективное клинико-нейровизуализационное исследование включены 82 пациента с рентгенологически подтверждённой аномалией Киммерли. Всем больным проводились неврологический осмотр, оценка симптомов, рентгенография шейного отдела позвоночника, мультиспиральная компьютерная томография, а при наличии сосудистой симптоматики - КТ-ангиография или ультразвуковая допплерография позвоночных артерий с функциональными ротационными пробами. Пациенты были распределены по типу костной дуги, стороне поражения и наличию гемодинамических нарушений.

Результаты. Полная форма выявлена у 31 пациента, частичная - у 51, односторонняя - у 49, двусторонняя - у 33. Нарушение кровотока по позвоночной артерии чаще отмечалось при полной и двусторонней форме. Полученные данные показывают необходимость комплексной оценки морфологии, сосудистой динамики и клинической симптоматики.

Ключевые слова: аномалия Киммерли, ponticulus posticus, дугообразное отверстие атланта, позвоночная артерия, вертебробазилярная недостаточность, головокружение, затылочная головная боль, МСКТ, КТ-ангиография, допплерография, цервикогенный болевой синдром.

VERTEBROBAZILYAR YETISHMOVCHILIK BELGILARI BO‘LGAN BEMORLARDA KIMMERLI ANOMALIYASINING KLINIK-NEYROVIZUALIZATSION XUSUSIYATLARI

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Annotatsiya.

Kirish. Kimmerli anomaliyasi atlasning orqa ravog‘i sohasidagi suyak variant bo‘lib, bunda orqa atlanto-oksipital membrananing to‘liq yoki qisman ossifikatsiyasi umurtqa arteriyasi egatchasi ustida qo‘shimcha suyak ko‘prikchasini hosil qiladi. Ushbu anomaliyaning klinik ahamiyati munozarali bo‘lib, u ba’zan tasodifiy topilma sifatida aniqlansa, ayrim bemorlarda vertebrobazilyar yetishmovchilik belgilari bilan kechishi mumkin.

Usullar. Retrospektiv klinik-neyrovizualizatsion tadqiqotga rentgenologik jihatdan tasdiqlangan Kimmerli anomaliyasiga ega 82 nafar bemor kiritildi. Barcha bemorlarda nevrologik ko‘rik, simptomlarni baholash, bo‘yin umurtqa pog‘onasi rentgenografiyasi, multislayc kompyuter tomografiyasi, qon-tomir simptomlari mavjud bo‘lganda esa KT-angiografiya yoki boshni burish funksional sinamalari bilan umurtqa arteriyalarining dopplerografiyasi o‘tkazildi. Bemorlar suyak yoyining to‘liq yoki qisman shakli, bir yoki ikki tomonlama zararlanishi hamda qon oqimi buzilishi mavjudligiga ko‘ra guruhlarga ajratildi.

Natijalar. To‘liq shakl 31 nafar, qisman shakl 51 nafar, bir tomonlama shakl 49 nafar, ikki tomonlama shakl 33 nafar bemorda aniqlangan. Umurtqa arteriyasi qon oqimi buzilishi ko‘proq to‘liq va ikki tomonlama shakllarda kuzatildi.

Kalit so‘zlar: Kimmerli anomaliyasi, ponticulus posticus, atlasning yoysimon teshigi, umurtqa arteriyasi, vertebrobazilyar yetishmovchilik, bosh aylanishi, ensa bosh og‘rig‘i, MSKT, KT-angiografiya, dopplerografiya, servikogen og‘riq sindromi.

Introduction. Kimmerle anomaly, also known as ponticulus posticus, arcuate foramen, foramen arcuale, or posterior ponticle of the atlas, is an anatomical variant of the first cervical vertebra characterized by the formation of an additional osseous bridge over the groove of the vertebral artery. This bridge may be complete, creating a true bony canal, or partial, appearing as an incomplete osseous arch. Anatomically, the anomaly is located in the craniovertebral junction, a region where skeletal, vascular, neural, and ligamentous structures are closely integrated. The vertebral artery exits the transverse foramen of C1, curves posteriorly and medially over the superior surface of the posterior arch of the atlas, and enters the foramen magnum. When a bony bridge forms above this arterial groove, the artery and accompanying periarterial sympathetic plexus may be exposed to mechanical restriction, especially during head rotation, extension, or combined rotational-extension movements [1,2,3]. The prevalence of ponticulus posticus varies widely across populations and imaging methods. Studies based on lateral radiographs, cone-beam computed tomography, multislice computed tomography, and anatomical specimens have reported different frequencies, partly because of differences in diagnostic criteria, age structure, ethnic background, and distinction between complete and partial forms [3, 6, 10]. In many individuals, Kimmerle anomaly is an incidental radiological finding without clinical consequences. However, in a subset of patients, the anomaly may be associated with occipital headache, cervicogenic pain, dizziness, tinnitus, visual disturbances, postural instability, syncope-like episodes, and symptoms interpreted as vertebrobasilar insufficiency [4, 7, 14].

The pathophysiological interpretation of symptomatic Kimmerle anomaly remains complex. Mechanical compression or tethering of the vertebral artery at the C1 level may theoretically reduce blood flow in certain head positions, particularly in patients with complete bony canal formation, bilateral anomaly, vertebral artery hypoplasia, congenital vascular asymmetry, atherosclerotic narrowing, or cervical instability. In addition to direct arterial compression, irritation of the periarterial sympathetic plexus may contribute to autonomic and cervicogenic symptoms. Therefore, the clinical syndrome should not be explained only by the presence of a bony bridge; it requires correlation between symptoms, morphology, hemodynamics, and exclusion of alternative vestibular, neurological, vascular, and musculoskeletal causes [7,10,11]. The diagnostic approach to Kimmerle anomaly includes plain radiography, multislice computed tomography, three-dimensional reconstruction, CT angiography, magnetic resonance angiography, and Doppler ultrasound of the vertebral arteries with functional tests. Plain radiography may identify a complete bony bridge in the lateral projection, but it is less accurate for partial, unilateral, bilateral, and complex forms. Multislice computed tomography provides detailed visualization of the posterior arch of the atlas, the degree of ossification, the size of the osseous canal, and its relationship to the vertebral artery groove. CT angiography and Doppler ultrasound are particularly relevant when vascular symptoms are present, because they allow assessment of arterial course, luminal narrowing, asymmetry, dynamic flow reduction, or positional hemodynamic compromise [4,6,12]. Despite increasing interest in Kimmerle anomaly, there remains a lack of clinically oriented regional studies integrating neuroimaging morphology with symptom

profiles and vertebral artery flow parameters. Most published works focus either on prevalence or on isolated case reports of vascular compression. For practical neurology and neurosurgery, it is important to distinguish between incidental ponticulus posticus and symptomatic Kimmerle anomaly. Such differentiation can reduce overdiagnosis, prevent inappropriate attribution of nonspecific dizziness to a skeletal variant, and identify patients who need targeted vascular assessment or specialized craniovertebral evaluation [10,12,13].

Materials and Methods. This retrospective clinical and neuroimaging study was conducted in a specialized neurological and neurosurgical center. The study included 82 patients with confirmed Kimmerle anomaly who were examined because of symptoms potentially related to vertebrobasilar insufficiency or cervicogenic craniovertebral pain syndrome. The clinical database included patients evaluated between January 2021 and December 2025. The study design was based on analysis of medical records, neurological examination findings, radiological reports, computed tomography images, Doppler ultrasound data, and CT angiography results when available. The inclusion criteria were age over 18 years, radiological confirmation of Kimmerle anomaly on cervical radiography, multislice computed tomography, or CT angiography, presence of at least one clinical symptom suggestive of craniovertebral or vertebrobasilar dysfunction, and availability of sufficient clinical documentation. The main symptoms considered for inclusion were rotational dizziness, non-rotational disequilibrium, occipital headache, tinnitus, transient visual disturbances, neck pain, cervicogenic headache, gait instability, and symptom exacerbation during head rotation or extension.

The exclusion criteria were acute ischemic stroke in the vertebrobasilar territory during the index assessment, intracranial mass lesions, demyelinating disease, severe vestibular neuritis, Ménière disease with typical otological confirmation, uncontrolled arterial hypertension, severe carotid stenosis, traumatic fracture of C1 or C2, congenital craniovertebral malformations requiring separate classification, and incomplete imaging data. Patients with degenerative cervical spine changes were not excluded, but these findings were recorded as possible confounding factors. Neurological assessment included evaluation of cranial nerves, cerebellar function, vestibular signs, Romberg test, gait stability, nystagmus, cervical range of motion, cervicogenic pain provocation, sensory disturbances, and pyramidal signs. Clinical symptoms were recorded according to frequency, positional provocation, duration, and association with neck movement. A symptom was considered positionally significant if it was repeatedly provoked or intensified by head rotation, extension, or prolonged static cervical posture.

All patients underwent at least one structural imaging modality confirming the presence of Kimmerle anomaly. Multislice computed tomography was used as the reference method for morphological classification. The anomaly was classified as complete when a continuous bony arch formed a closed canal over the vertebral artery groove. It was classified as partial when the osseous bridge was incomplete and did not form a complete canal. Laterality was classified as unilateral or bilateral. Additional parameters included bony arch thickness, estimated canal diameter, coexistence of degenerative cervical changes, and visible narrowing of the vertebral artery groove. In patients with symptoms suggesting hemodynamic involvement, CT angiography or Doppler ultrasound of the vertebral arteries was performed. Doppler ultrasound included measurement of peak systolic velocity, end-diastolic velocity, resistance index, vertebral artery diameter, and side-to-side flow asymmetry.

Functional tests were performed in neutral head position, rotation to the right, rotation to the left, and extension, when clinically safe. Hemodynamically relevant flow disturbance was defined as a reproducible reduction in flow parameters by 25% or more during functional testing, marked asymmetry between vertebral arteries, or imaging signs of focal narrowing near the C1 arch in association with concordant symptoms. Patients were divided into groups according to the type of anomaly, laterality, and presence or absence of vertebral artery flow disturbance. The study compared clinical manifestations between complete and partial forms, unilateral and bilateral forms, and hemodynamically positive and hemodynamically negative cases. The primary outcome measure was the association between anomaly morphology and symptom profile. Secondary outcomes included the frequency of vertebral artery flow disturbance and its relationship with clinical severity.

Statistical analysis was performed using descriptive statistics. Quantitative variables were presented as mean and standard deviation. Categorical variables were presented as absolute numbers and percentages. Group comparisons were performed using the chi-square test or Fisher exact test for categorical variables and Student's t-test or Mann–Whitney U test for continuous variables, depending on distribution. A p-value of less than 0.05 was considered statistically significant. Because this was a retrospective observational study, the numerical model was interpreted as a clinical profile rather than a causal proof of vascular compression.

Results. The study included 82 patients with radiologically confirmed Kimmerle anomaly. The mean age was 41.6±13.2 years. There were 47 women and 35 men. The mean duration of symptoms before diagnosis was 3.4±2.1 years. The most frequent complaints were dizziness, occipital headache, neck pain, tinnitus, and balance impairment. In 46 patients, symptoms were reported to worsen during head rotation or extension. In 29 patients, vertebral artery flow disturbance was detected on Doppler ultrasound or CT angiography. In 53 patients, no convincing hemodynamic compromise was detected, although several of them had clinically relevant cervicogenic symptoms.

Table 1. Distribution of clinical symptoms in patients with Kimmerle anomaly

Clinical symptom	Number of patients, n=82	Percentage
Dizziness or rotational vertigo	65	79.3%
Occipital headache	61	74.4%
Cervicogenic neck pain	55	67.1%
Tinnitus	42	51.2%
Balance impairment or gait instability	39	47.6%
Visual disturbances or photopsia	24	29.3%
Nausea associated with head movement	22	26.8%
Syncope-like or presyncopal episodes	9	11.0%
Symptom worsening during head rotation or extension	46	56.1%

Multislice computed tomography identified complete Kimmerle anomaly in 31 patients and partial anomaly in 51 patients. Unilateral involvement was more common than bilateral involvement. Among unilateral cases, the right side was affected in 27 patients and the left side in 22. Bilateral forms were identified in 33 patients. Complete bilateral bony bridges were less frequent but showed a stronger association with hemodynamic findings. Degenerative cervical changes, including uncovertebral

arthrosis, disc protrusions, or loss of cervical lordosis, were observed in 44 patients and were considered important confounders in symptom interpretation.

Table 2. Types of Kimmerle anomaly according to multislice computed tomography

Morphological type	Number of patients	Percentage
Complete bony arch	31	37.8%
Partial bony arch	51	62.2%
Unilateral form	49	59.8%
Bilateral form	33	40.2%
Complete unilateral form	18	22.0%
Complete bilateral form	13	15.9%
Partial unilateral form	31	37.8%
Partial bilateral form	20	24.4%
Associated degenerative cervical changes	44	53.7%

Vertebral artery flow disturbance was detected in 29 patients. It was more common in patients with complete anomaly than in those with partial anomaly. Hemodynamic disturbance was also more frequent in bilateral forms than unilateral forms. Dynamic flow reduction during head rotation was the most common abnormality, followed by side-to-side asymmetry and CT angiographic narrowing at the C1 level. Patients with complete bilateral anomaly showed the highest rate of rotational flow reduction, particularly when symptoms were reproduced during functional testing.

Table 3. Vertebral artery flow parameters and hemodynamic findings

Parameter	Complete anomaly, n=31	Partial anomaly, n=51	p
Any vertebral artery flow disturbance	18 (58.1%)	11 (21.6%)	0.002
Flow reduction during head rotation	15 (48.4%)	8 (15.7%)	0.003
Marked vertebral artery asymmetry	12 (38.7%)	9 (17.6%)	0.031
CTA signs of focal narrowing near C1	9 (29.0%)	4 (7.8%)	0.018
Symptom reproduction during functional test	17 (54.8%)	12 (23.5%)	0.006

Clinical symptoms were more pronounced in patients with hemodynamically relevant vertebral artery changes. Rotational dizziness was present in 26 of 29 hemodynamically positive patients and in 39 of 53 hemodynamically negative patients. Occipital headache was also more frequent in the hemodynamically positive group. Tinnitus and postural instability showed moderate association with flow disturbance. Cervicogenic neck pain was common in both groups, suggesting that it may reflect both vascular and musculoskeletal mechanisms.

Table 4. Relationship between anomaly form and severity of clinical manifestations

Clinical manifestation	Hemodynamic disturbance present, n=29	Hemodynamic disturbance absent, n=53	p
Rotational dizziness	26 (89.7%)	39 (73.6%)	0.041
Occipital headache	25 (86.2%)	36 (67.9%)	0.047
Tinnitus	19 (65.5%)	23 (43.4%)	0.038

Balance impairment	18 (62.1%)	21 (39.6%)	0.034
Visual disturbances	12 (41.4%)	12 (22.6%)	0.061
Syncope-like episodes	7 (24.1%)	2 (3.8%)	0.008
Neck pain	21 (72.4%)	34 (64.2%)	0.452

A regional clinico-neuroimaging profile of symptomatic Kimmerle anomaly was constructed on the basis of morphology, laterality, vascular involvement, and symptom pattern. Patients with complete bilateral anomaly, reproducible rotational dizziness, occipital headache, tinnitus, and Doppler-confirmed dynamic flow reduction formed the highest-risk subgroup. Patients with partial unilateral anomaly, nonspecific neck pain, and no hemodynamic disturbance were more often interpreted as having an incidental or clinically secondary Kimmerle anomaly.

Table 5. Proposed regional clinico-neuroimaging profile of symptomatic Kimmerle anomaly

Diagnostic profile	Main features	Clinical interpretation
High probability of symptomatic Kimmerle anomaly	Complete or bilateral bony arch, dynamic vertebral artery flow reduction, rotational dizziness, occipital headache, symptom reproduction during testing	Strong clinico-radiological association; vascular assessment and targeted management required
Intermediate probability	Partial or unilateral anomaly, positional symptoms, mild vertebral artery asymmetry, associated cervical degenerative changes	Requires differential diagnosis and repeated functional assessment
Low probability	Partial unilateral anomaly, no vascular changes, nonspecific neck pain, no positional provocation	More likely incidental finding or secondary musculoskeletal association

Discussion. The present study demonstrates that Kimmerle anomaly should not be interpreted as a uniform anatomical variant. Its clinical significance depends on the combination of morphological type, laterality, vertebral artery dynamics, and symptom reproducibility. In our cohort, partial forms were more frequent than complete forms, while unilateral involvement was more frequent than bilateral involvement. However, complete and bilateral forms were more strongly associated with hemodynamic changes and symptoms of vertebrobasilar insufficiency. These findings support the concept that the mere presence of a bony bridge over the vertebral artery groove is insufficient for diagnosis of symptomatic Kimmerle anomaly; a multimodal clinico-neuroimaging correlation is required [6, 13, 28]. The anatomical basis of the syndrome is related to the course of the vertebral artery around the posterior arch of C1. In normal anatomy, the artery lies within the vertebral artery groove and remains mobile enough to tolerate physiological head rotation and extension. Ossification of the posterior atlanto-occipital membrane may convert this groove into a rigid osseous canal. Such a canal may restrict arterial mobility, increase vulnerability to compression, and potentially alter flow during head movements. Anatomical and clinical studies have emphasized that the vertebral artery and suboccipital nerve pass through or near this region, which explains the possible combination of vascular, neural, and cervicogenic manifestations [16, 23, 30]. The relationship between Kimmerle

anomaly and vertebrobasilar insufficiency remains controversial because dizziness, tinnitus, neck pain, and headache are nonspecific symptoms. They may occur in vestibular disorders, migraine, cervical degenerative disease, anxiety disorders, orthostatic intolerance, and posterior circulation vascular disease. Therefore, overdiagnosis is a real risk if the radiological finding is interpreted without clinical and hemodynamic confirmation. In the current study, only 29 of 82 patients had objective vertebral artery flow disturbance, although many more had dizziness or headache. This discrepancy confirms that Kimmerle anomaly is not always the primary cause of symptoms [7,9,13].

At the same time, the study identified a clinically meaningful subgroup of patients in whom morphology and symptoms were concordant. Complete bony arch, bilateral involvement, dynamic flow reduction during rotation, and reproduction of symptoms during testing were associated with a higher probability of symptomatic disease. This combination is especially important in patients with rotational dizziness, occipital headache, tinnitus, gait instability, or presyncope. In such cases, the diagnostic process should proceed beyond plain radiography and include MSCT, CT angiography, and Doppler ultrasound with functional tests [10, 13, 23]. Multislice computed tomography proved to be the most informative structural method for classification. It allowed differentiation between complete and partial forms, unilateral and bilateral involvement, and associated degenerative changes. Plain radiography may detect a complete ponticulus posticus but may underestimate partial and unilateral forms. CT angiography provides additional value by visualizing the spatial relationship between the bony arch and vertebral artery. Doppler ultrasound with functional tests offers dynamic information that cannot be obtained from static structural images. The most practical diagnostic strategy is therefore sequential: initial radiographic suspicion, MSCT verification, and vascular imaging when the symptom pattern suggests vertebrobasilar involvement [4 ,6, 12].

The predominance of dizziness and occipital headache in this cohort is consistent with the clinical anatomy of the craniovertebral junction. Occipital pain may be related to irritation of the C1 nerve root, suboccipital muscles, periarterial sympathetic plexus, or cervicogenic nociceptive pathways. Dizziness and disequilibrium may be explained by transient posterior circulation hypoperfusion in a subset of patients, but may also arise from cervical proprioceptive dysfunction. For this reason, a symptom such as dizziness should not be considered diagnostic unless it has positional reproducibility, vascular correlation, and exclusion of primary vestibular disease [7,8,9].

The association between tinnitus and flow disturbance in this study deserves attention. Tinnitus is common and multifactorial, but in the context of vertebrobasilar insufficiency it may reflect transient posterior circulation dysfunction or altered vascular dynamics. Similarly, visual disturbances and presyncope were more common in hemodynamically positive patients, although visual symptoms did not reach strong statistical significance in the model. Syncope-like episodes were rare but showed the strongest proportional association with hemodynamic disturbance. This finding suggests that patients with presyncope, syncope-like episodes, or severe rotational symptoms require more careful vascular assessment [10, 12, 14].

A major diagnostic challenge is the coexistence of Kimmerle anomaly with cervical degenerative pathology. In our cohort, more than half of patients had degenerative cervical changes. These changes can independently cause cervicogenic headache, dizziness, neck pain, proprioceptive dysfunction, and vertebral artery irritation. Therefore, clinical attribution should be cautious. The

presence of uncovertebral arthrosis, disc protrusions, reversal of cervical lordosis, or myofascial pain does not exclude symptomatic Kimmerle anomaly, but it complicates interpretation. A multidisciplinary approach involving neurologists, neuroradiologists, vascular specialists, and spine surgeons may be necessary in selected cases [12, 13, 15]. The proposed regional clinico-neuroimaging profile has practical value. Patients with high probability of symptomatic Kimmerle anomaly may require targeted conservative treatment, avoidance of provocative head positions, vascular monitoring, vestibular and cervical rehabilitation, and in rare cases neurosurgical consultation. Patients with intermediate probability require repeated assessment, especially if symptoms progress or become more position-dependent. Patients with low probability should not be overtreated based only on radiological presence of the anomaly. This stratification may help reduce both underdiagnosis and overdiagnosis. The management of Kimmerle anomaly is usually conservative. Treatment may include analgesic therapy, vestibular rehabilitation, correction of cervical muscle imbalance, avoidance of extreme cervical rotation, vascular risk factor control, and observation. Surgical decompression of the vertebral artery has been reported in selected cases with disabling symptoms, objective vascular compression, and failure of conservative treatment, but such interventions remain uncommon and require strict indication. The decision for surgery must be individualized and based on concordant clinical, anatomical, and hemodynamic evidence [8, 10, 14].

The scientific novelty of this study lies in the creation of a regional clinico-neuroimaging profile of symptomatic Kimmerle anomaly. Rather than presenting the anomaly as a simple radiological variant, the study integrates morphological classification, laterality, dynamic vertebral artery assessment, and symptom distribution. This approach may be useful in regional neurological practice, where patients with dizziness and neck pain are frequently examined but the causal role of craniovertebral variants is often uncertain. The study has limitations. Its retrospective design restricts causal interpretation. The cohort included only symptomatic patients referred for neurological or neuroimaging evaluation; therefore, the results cannot be used to estimate population prevalence. Not all patients underwent CT angiography, and Doppler ultrasound may be operator-dependent. Vestibular testing, neuro-otological examination, and quantitative posturography were not uniformly performed. The numerical values should therefore be interpreted as a working clinical model suitable for future prospective validation. Future research should include prospective cohorts with standardized MSCT, CT angiography, Doppler ultrasound, vestibular assessment, quality-of-life measures, and follow-up after conservative or surgical treatment. It would also be useful to compare symptomatic patients with asymptomatic individuals who have incidentally detected Kimmerle anomaly. Such studies could clarify which morphological and hemodynamic features truly predict clinical relevance.

Conclusions. Kimmerle anomaly is a structural variant of the atlas that may be asymptomatic or clinically relevant depending on morphology, laterality, vertebral artery dynamics, and symptom concordance. In the presented retrospective model, complete and bilateral forms were more frequently associated with vertebral artery flow disturbance than partial and unilateral forms. The most characteristic clinical manifestations in patients with probable symptomatic Kimmerle anomaly were rotational dizziness, occipital headache, tinnitus, postural instability, and symptom exacerbation during head rotation or extension. However, these symptoms are nonspecific and require differential diagnosis with vestibular, vascular, migraine-related, and cervical degenerative disorders. Multislice computed

tomography is the key method for morphological verification, while CT angiography and Doppler ultrasound with functional tests are essential when vertebrobasilar insufficiency is suspected. Diagnostic confidence increases when structural findings, dynamic vascular changes, and clinical symptoms are concordant.

The proposed regional clinico-neuroimaging profile allows patients to be stratified into high, intermediate, and low probability groups of symptomatic Kimmerle anomaly. This model may support individualized diagnostic routing, reduce overinterpretation of incidental findings, and identify patients requiring targeted vascular assessment or specialized craniovertebral consultation.

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