

Investigation of the Frequency of Condylar Canal Variations and Their Relationship with Clinical Symptoms

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ABSTRACT

Objective: The condylar canal (CC) is an important anatomical structure located in the posterior cranial fossa and frequently exhibits variations that may influence surgical approaches and clinical interpretation. This study aimed to investigate the frequency of CC variations and evaluate their possible relationship with clinical findings.

Materials and Methods: A total of 113 cranial CT scans (34 females and 79 males) were retrospectively analyzed, and detailed morphometric measurements of the foramen magnum and CC were performed. In addition, anamnesis data regarding clinical symptoms, including headache, nausea, dizziness, neck pain, blurred vision, and epistaxis, were assessed.

Results: The results demonstrated that the CC was absent in some individuals, unilateral in others, and bilateral in a considerable proportion. However, no statistically significant associations were found between CC variations and patient demographics or clinical symptoms ($p>0.05$). Similarly, morphometric analysis of the foramen magnum revealed no significant differences among the groups ($p>0.05$).

Conclusion: These findings suggest that although the CC demonstrates considerable anatomical variability, its presence or absence does not appear to correlate with clinical symptoms. Our study provides valuable radiological and anatomical data that may help neurosurgeons, radiologists, and anatomists better understand CC variations. To our knowledge, this is among the first studies to examine CC variations together with clinical symptomatology, thereby providing new insights into the literature.

Keywords: Anatomical variation, clinical correlation, computed tomography, condylar canal, foramen magnum.



INTRODUCTION

The functional significance of the condylar canal (CC) lies in its role as the primary osseous conduit for the posterior condylar emissary vein (PCEV), which constitutes a critical collateral connection between the intracranial sigmoid sinus and the extracranial vertebral venous plexus.¹ Under normal physiological conditions, cerebral venous outflow occurs predominantly through the internal jugular veins. However, during positional changes, jugular vein compression, or states of increased intracranial pressure, emissary veins act as essential safety valves that help maintain hemodynamic equilibrium within the posterior cranial fossa. From a mechanistic perspective, structural variations of the CC, such as critical narrowing (hypoplasia) or complete absence (agenesis), can significantly restrict this alternative venous drainage pathway. This restriction may potentially trigger localized venous congestion and transient retro-obstruent hypertension within the dural sinuses. Such altered venous dynamics are well-known triggers for the activation of perivascular nociceptive fibers within the dura mater, clinically manifesting as chronic or tension-type suboccipital headaches. Furthermore, venous congestion extending toward the petrosal and internal auditory veins may directly disrupt the microfluidic environment of the inner ear, providing a plausible biological rationale for neuro-otological symptoms such as pulsatile tinnitus, vertigo, and dizziness. Therefore, assessment of the morphometric configuration of the CC is not merely an anatomical exercise but may also be important for understanding unexplained posterior fossa symptomatology.^{2–5}

The CC is situated in the fossa condylaris, posterior to the hypoglossal canal and within the lower part of the jugular foramen.^{6–8} The condylar canal and the accompanying emissary vein represent important anatomical landmarks in skull base surgical procedures. Functionally, the condylar canal provides a conduit that facilitates communication between the intracranial and extracranial compartments.⁸ Condylar emissary veins, meningeal arteries, and nerves supplying the dura mater pass through this canal in the posterior cranial fossa.⁹ The condylar canal has also been referred to as the condyloid canal, condylar foramen, and posterior condylar canal.^{10,11} The hypoglossal canal, also known as the anterior condylar canal, is distinct from the posterior condylar canal.⁸

In clinical conditions associated with impaired cranial venous drainage, such as intracranial hypertension, vascular malformations, and internal jugular vein obstruction, emissary veins may provide alternative pathways to facilitate venous drainage.¹⁰ The posterior condylar vein is a major emissary vein of the cranial venous system. It establishes a venous connection between the vertebral venous plexus and the sigmoid-jugular

KEY MESSAGES

- Multiplanar CT reconstructions revealed considerable normal variation in condylar canal anatomy.
- Bilateral, unilateral, and absent condylar canal variants showed a balanced distribution. No statistically significant correlation was found between these variants and neuro-otological symptoms.
- Morphometric dimensions of the foramen magnum did not differ significantly among the groups. Documentation of these osseous landmarks is essential to avoid iatrogenic skull base injuries.

venous complex. This vein is observed more commonly on the right side than on the left. The higher prevalence of the condylar canal on the right has been attributed to a more direct venous pathway to the heart, which may increase the likelihood of emissary foramen formation on that side.⁶

The condylar foramen represents one of the largest emissary foramina of the skull. The posterior condylar vein passing through this foramen provides a significant alternative pathway for venous outflow, particularly when drainage into the sigmoid sinus-jugular venous complex is compromised.¹² Venous imaging studies in patients with achondroplasia and complex craniosynostosis have demonstrated venous outflow obstruction at the skull base, with the jugular foramina being particularly affected.¹³ Anatomically, the condylar canal represents a variable osseous pathway in the posterior cranial base that allows venous communication between the intracranial and extracranial compartments.¹⁴

Accurate skull base morphometry is crucial for reducing morbidity and mortality in craniovertebral surgery.⁸ In addition to examination in dry bones, CT and MRI are used to visualize the condylar canal.⁸ Although the morphological variability of the condylar canal and its emissary veins is well documented in the classical osteological literature, there remains a substantial paucity of objective clinical data investigating whether these structural variations directly affect patient symptomatology. In this study, we primarily hypothesized that individuals with complete bilateral absence (agenesis) or severe hypoplasia of the condylar canal would exhibit a significantly higher prevalence of congestion-related neuro-otological symptoms, such as persistent suboccipital headache, dizziness, or tinnitus, due to structural restriction of collateral venous outflow pathways from the posterior cranial fossa. Therefore, the objective of this retrospective study was to determine the frequency and dimensions of CC variations using multiplanar computed tomography (CT) reconstructions

and to systematically analyze their potential correlations with documented clinical symptoms, thereby bridging the gap between gross anatomy and neurosurgical practice.

MATERIALS AND METHODS

This retrospective study included 113 patients, both adults and children (34 females and 79 males; age range, 11–98 years), who underwent routine cranial computed tomography (CT) examinations at Malatya Turgut Özal University. The primary indications for CT imaging included evaluation of chronic nonspecific headache, exclusion of acute neurological events, and neuro-otological assessment.

Patients with poor image quality; motion or metal artifacts; previous skull base or neurosurgical procedures; craniovertebral junction anomalies; bone tumors involving the occipital region; traumatic cranial injuries; or lesions affecting the condylar canal were excluded from the study.

All CT datasets were obtained using a standardized protocol with a 3-mm slice thickness and were analyzed using RadiAnt DICOM Viewer software. The study protocol was approved by the Malatya Turgut Özal University Non-Interventional Clinical Research Ethics Committee (Approval Number: 2022/136, Date: 05.09.2022).

The presence, absence, and morphometric characteristics of the condylar canal were independently evaluated by one neurosurgeon and three senior anatomists. Interobserver reliability was assessed using the intraclass correlation coefficient (ICC). The ICC was 0.91 (95% CI, 0.87–0.94), indicating excellent agreement among observers.

Groups and Measurement Parameters

Group 1: This group included crania with bilateral CCs (Fig. 1).

CCD: Distance between the two condyles.

CCTD: Transverse diameter of the CCs (right and left) (Fig. 2).

CCSD: Anteroposterior diameter of the CCs (right and left) (Fig. 3a).

CCBC-A: Angle between the CC and the cranial base.

CCBC-D: Distance between the CC and the skull base on axial sections.

CCFM-A: On the sagittal axis extending anteroposteriorly through the foramen magnum, the angle between the line extending from the right CC and the transverse axis extending between the CCs.

FMS: Anteroposterior diameter of the foramen magnum (Fig. 3b).

FMT: Transverse diameter of the foramen magnum (Fig. 4a).

Group 2: This group included individuals without a CC (Fig. 4b). Only the transverse and sagittal diameters of the foramen magnum were examined in this group.

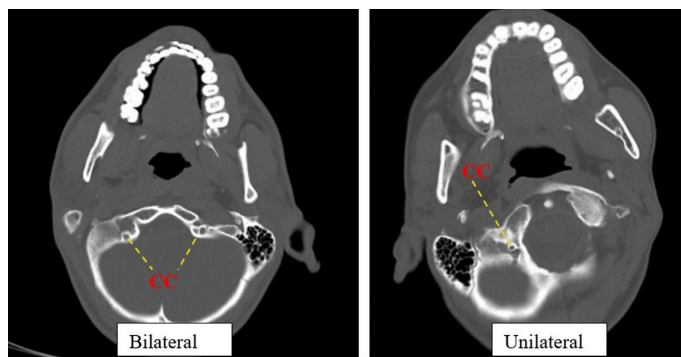


Figure 1. Bilateral and unilateral condylar canals (CCs). Computed tomography (CT) images demonstrating CC morphology. Examples of bilateral and unilateral CCs are shown.

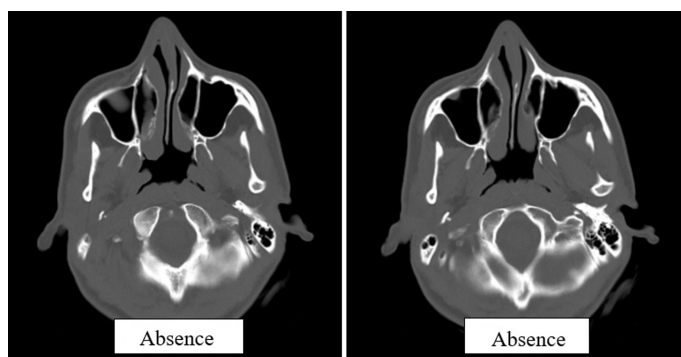


Figure 2. Transverse diameter of the condylar canal (CCTD). Measurement of the transverse diameter of the CC (CCTD) on axial CT images. The maximum mediolateral diameter of the canal was measured.

FMS: Anteroposterior diameter of the foramen magnum.

FMT: Transverse diameter of the foramen magnum.

FMD: Diameter of the foramen magnum.

Group 3: This group included crania with a unilateral CC.

CCTD: Transverse diameter of the CC (right or left).

CCSD: Anteroposterior diameter of the CC (right or left).

CCBC-A: Angle between the CC and the cranial base.

FMS: Anteroposterior diameter of the foramen magnum.

FMT: Transverse diameter of the foramen magnum.

Sample Size Determination

The adequacy of the sample size was determined using an a priori power analysis performed with G*Power software (Version 3.1; Heinrich Heine University, Düsseldorf,

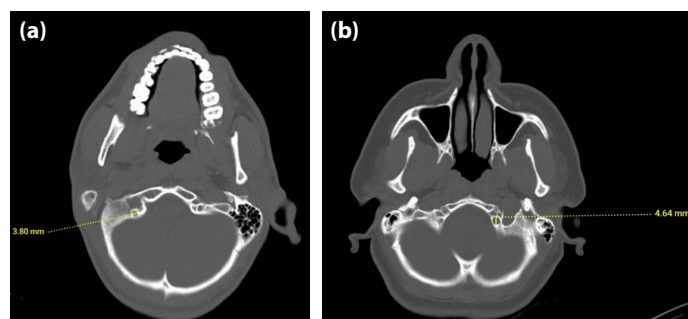


Figure 3. (a) Anteroposterior diameter of the condylar canal (CCSD). Measurement of the anteroposterior diameter of the CC (CCSD) on axial CT images. The maximum anteroposterior dimension was recorded. **(b)** Anteroposterior diameter of the foramen magnum (FMS). Measurement of the anteroposterior diameter of the foramen magnum (FMS) on axial CT images, defined as the distance between the basion and opisthion.

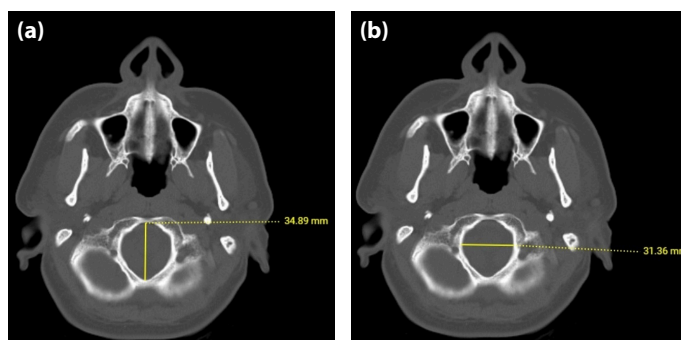


Figure 4. (a) Transverse diameter of the foramen magnum (FMT). Measurement of the transverse diameter of the foramen magnum (FMT) on axial CT images, defined as the maximum mediolateral distance. **(b)** Absence of the condylar canal (CC) in different patients. CT images illustrating the absence of the CC in different patients. Unilateral and bilateral absence of the canal is demonstrated.

Germany). Because this study is among the first to evaluate the relationship between condylar canal variations and clinical symptoms, no previous literature was available from which to derive a specific reference effect size. Therefore, a moderate effect size of 0.30 was assumed in accordance with Cohen's criteria. Based on this moderate effect size of 0.30, a significance level (α) of 0.05, a statistical power of 0.95, and a 95% confidence level, the minimum required sample size was calculated as 111 participants. Consequently, the final study sample of 113 patients was considered sufficient to achieve adequate statistical power for detecting meaningful clinical effects.

Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics for Windows, Version 25.0 (IBM Corp., Armonk, NY, USA). The normality of continuous variables was assessed using the Shapiro–Wilk test. Distributional characteristics of the data were used to determine whether parametric or nonparametric statistical methods were appropriate. Continuous variables were presented as mean $\pm$ standard deviation (SD) for normally distributed data and as median with minimum and maximum values for nonnormally distributed data. Categorical variables were expressed as frequencies and percentages. Homogeneity of variances was evaluated using Levene's test. Comparisons among three or more independent groups were performed using the Kruskal–Wallis test for nonnormally distributed data. When significant differences were identified, post hoc pairwise comparisons were performed using the Mann–Whitney U test with Bonferroni correction to control for multiple comparisons. Categorical variables were analyzed using contingency tables

and the chi-square (χ^2) test. A two-tailed p-value of <0.05 was considered statistically significant.¹⁵ The ICC was used to assess interrater reliability.

RESULTS

The anatomical and morphometric dimensions of the condylar canal (CC) demonstrated wide normal variations across the study population. Among the 113 patients analyzed, a bilateral CC configuration was observed in 35 patients, a unilateral CC was identified in 38 patients, and the canal was completely absent (agenesis) in 40 patients. Demographic analysis revealed no statistically significant differences among these morphological groups in terms of sex distribution ($\chi^2=3.636$, $p=0.162$). Similarly, no statistically significant differences were detected among the groups in terms of age distribution ($H=0.753$, $p=0.686$), with a mean age of 46.13 ± 23.29 years in the absent group, 48.63 ± 23.88 years in the unilateral group, and 51.46 ± 26.96 years in the bilateral group. Furthermore, clinical history findings revealed no statistically significant associations between specific CC variations and patient symptoms ($p>0.05$) (Table 1, 2).

The anatomical and morphometric dimensions of the condylar canal demonstrated wide normal variations between the unilateral and bilateral groups, as detailed below. In our study population, no statistically significant differences were observed among the morphological groups according to age or sex ($p>0.05$). The condylar canal was observed to be unilateral, bilateral, or completely absent across the cohorts. According to the clinical history findings, no statistically significant differences were detected among the

Table 1. Comparison of demographic characteristics (age and sex) according to condylar canal status

Variables	Group/value	Absent	Unilateral	Bilateral	Total	χ^2 /Kruskal–Wallis	p
Sex	Female, n	8	15	11	34	3.636	0.162
	Female, %	20.0	39.5	31.4	30.1		
	Male, n	32	23	24	79		
	Male, %	80.0	60.5	68.6	69.9		
Age (years)	Mean $\pm$ SD	46.13 $\pm$ 23.29	48.63 $\pm$ 23.88	51.46 $\pm$ 26.96	—	0.753	0.686
	Median (min–max)	40.5 (11–85)	44.5 (12–98)	48 (16–97)	—		

SD: Standard deviation; Min: Minimum; Max: Maximum. Statistical significance was set at $p < 0.05$.**Table 2.** Comparison of clinical symptoms according to condylar canal status

Variables	Absent	Unilateral	Bilateral	Total	χ^2	p
Symptoms					17.435	0.134
Asymptomatic, n	5	4	1	10		
Asymptomatic, %	12.5	10.5	2.9	8.8		
Headache, n	17	18	21	56		
Headache, %	42.5	47.4	60.0	49.6		
Nausea, n	8	6	4	18		
Nausea, %	20.0	15.8	11.4	15.9		
Dizziness/imbalance, n	5	2	2	9		
Dizziness/imbalance, %	12.5	5.3	5.7	8.0		
Neck pain, n	2	5	2	9		
Neck pain, %	5.0	13.2	5.7	8.0		
Blurred vision, n	3	0	3	6		
Blurred vision, %	7.5	0.0	8.6	5.3		
Epistaxis, n	0	3	2	5		
Epistaxis, %	0.0	7.9	5.7	4.4		

Statistical significance was set at $p < 0.05$.**Table 3.** Comparison of transverse and sagittal measurements of the foramen magnum among the groups

Variable	Group	Mean $\pm$ SD	Median (min–max)	Kruskal–Wallis test	p
FMTD (mm)	Absent	22.0 $\pm$ 5.6	23.3 (12.5–35.1)	1,584	0,453
	Unilateral	23.0 $\pm$ 4.6	21.9 (13.3–30.6)		
	Bilateral	24.0 $\pm$ 4.6	24.5 (17.1–33.6)		
FMSD (mm)	Absent	18.3 $\pm$ 6.0	17.5 (10.1–30.7)	0,229	0,892
	Unilateral	19.6 $\pm$ 7.4	16.0 (10.4–33.3)		
	Bilateral	20.0 $\pm$ 8.5	16.7 (10.8–40.2)		

SD: Standard deviation; Min: Minimum; Max: Maximum; FMTD: Transverse diameter of the foramen magnum; FMSD: Sagittal diameter of the foramen magnum. Statistical significance was set at $p < 0.05$.

groups regarding patient symptoms ($p > 0.05$). Furthermore, morphometric analysis of the foramen magnum dimensions across all study cohorts demonstrated no statistically

significant differences ($p > 0.05$) (Table 3). Measurements showed that the CC could be unilateral, bilateral, or completely absent (Table 4–6) (Fig. 1, 2). According to the

Table 4. Descriptive morphometric measurements of the foramen magnum in the absent condylar canal group

Variables	Mean±SD	Median (min–max)
FMT (mm)	22.0±5.6	23.3 (12.5–35.1)
FMS (mm)	18.3±6.0	17.5 (10.1–30.7)

SD: Standard deviation; Min: Minimum; Max: Maximum; FMT: Transverse diameter of the foramen magnum; FMS: Sagittal diameter of the foramen magnum.

Table 5. Morphometric measurements in the unilateral condylar canal group (mm)

Variables	Mean±SD	Median (min–max)
CCTD (right) (mm)	3.07±0.84	3.13 (1.59–4.64)
CCSD (left) (mm)	2.26±0.86	2.05 (0.95–3.96)
FMTD (mm)	23.0±4.6	21.9 (13.3–30.6)
FMSD (mm)	19.6±7.4	16.0 (10.4–33.3)
FMD (mm)	26.42±6.33	24.7 (15.07–38.7)

SD: Standard deviation; Min: Minimum; Max: Maximum; CC: Condylar canal; CCTD: Transverse diameter of the condylar canal; CCSD: Sagittal diameter of the condylar canal; FMTD: Transverse diameter of the foramen magnum; FMSD: Sagittal diameter of the foramen magnum; FMD: Diameter of the foramen magnum.

clinical history findings, there was no statistically significant difference among the CC groups ($p>0.05$) (Table 2). In all groups, there were no statistically significant differences in the transverse and sagittal measurements of the foramen magnum ($p>0.05$) (Table 3).

DISCUSSION

Precise and comprehensive mapping of skull base anatomy is of paramount importance for neurosurgeons and neuroradiologists to optimize surgical trajectories and avoid iatrogenic neurovascular injuries. The current literature includes a substantial body of morphometric data concerning the condylar canal (CC) and its anatomical variations, predominantly derived from dry osteological specimens.^{1,16–21} However, misinterpretation of these normal variants as osteolytic lesions, pathological fractures, or dural arteriovenous fistulas remains a critical diagnostic pitfall in clinical practice. To the best of our knowledge, the present study represents the first multiplanar computed tomography (CT) investigation specifically designed to correlate these cross-sectional structural variations with a defined set of clinical neuro-otological symptoms. By combining the expertise of anatomists, radiologists, and neurosurgeons, this multidisciplinary study aimed to address an important gap in the literature by determining whether these osseous polymorphisms have subtle subclinical manifestations or actively contribute to the pathogenesis of specific patient complaints.

Table 6. Morphometric measurements in the bilateral condylar canal group

Variables	Mean±SD	Median (min–max)
CCTD (right) (mm)	3.57±0.71	3.52 (2.06–5.09)
CCSD (right) (mm)	2.67±0.97	2.49 (0.91–5.01)
CCTD (left) (mm)	3.31±0.77	3.28 (1.81–5.10)
CCSD (left) (mm)	2.47±1.05	2.11 (0.98–4.95)
CCD (mm)	41.9±11.5	39.9 (24.3–76.0)
FMTD (mm)	24.0±4.6	24.5 (17.1–33.6)
FMSD (mm)	20.0±8.5	16.7 (10.8–40.2)
CCBC-D (right) (mm)	5.35±1.65	5.67 (2.68–8.51)
CCBC-D (left) (mm)	4.95±1.59	5.29 (1.55–7.60)

SD: Standard deviation; Min: Minimum; Max: Maximum; CC: Condylar canal; CCTD: Transverse diameter of the condylar canal; CCSD: Sagittal diameter of the condylar canal; CCD: Distance between the two condylar canals; FMTD: Transverse diameter of the foramen magnum; FMSD: Sagittal diameter of the foramen magnum; CCBC-D: Distance between the condylar canal and the skull base on axial sections.

No statistically significant difference has been reported between sexes in the prevalence of the intermediate condylar canal.^{14,22,23} In our study, there was no statistically significant difference among the groups according to age or sex ($p>0.05$). The similar findings in our study may indicate that sex does not affect the presence of the canal. Although the CC may be present unilaterally or bilaterally, it may also be completely absent in some individuals.²⁴ According to Boyd et al.,²⁴ the posterior condylar canal was detected bilaterally in 46.6% of cases, was absent in 23.81%, was present only on the right side in 16.5%, and was present only on the left side in 13.88%. Ginsberg et al.¹ reported that the canal was present bilaterally in 55.9% of cases and unilaterally in 17.9%. Tatar et al.¹⁸ assessed the bilateral presence of the CC and reported that it was observed on the left side in 22 of 32 skulls (68.75%) and on the right side in 19 (61.2%). Kumar et al.²⁵ observed that the CC was present bilaterally in 48.33% of cases, unilaterally on the left in 18.33%, unilaterally on the right in 15%, and was completely absent in 16.66%. Muthukumar et al.⁶ found the CC on the right side in 4 crania and on the left side in 16 crania. Dakshayani and Shivanal¹⁹ observed that the posterior condylar canal was present bilaterally in 36% of cases, unilaterally on the left in 24%, unilaterally on the right in 20%, and was completely absent in 20%. Among the participants in our study, three groups were identified: those with unilateral CC (39.5% female, 60.5% male), those with bilateral CC (31.4% female, 68.6% male), and those without CC (20% female, 80% male). The distribution of CC variations in our study was consistent with the literature. In addition, clinical data related to CC variations were evaluated, and no statistically significant

differences were detected among the groups according to the clinical history findings. Therefore, CC variation did not appear to be associated with a distinct clinical presentation. Intermediate CC was not observed in our study; similarly, Smith et al.¹⁴ reported a prevalence of 3% for intermediate CC and found no statistically significant difference between sexes. The reported anatomical dimensions indicate an approximate sagittal diameter of 35 mm and a transverse diameter of 30 mm.²⁶ Muthukumar et al.⁶ reported a mean foramen magnum length of 36.75 ± 2.50 mm, an anteroposterior length of 33.3 mm, and a width of 27.9 mm.

The mean morphometric measurements of the foramen magnum, including both transverse and sagittal diameters, were expressed in millimeters (mm) in accordance with international anatomical reporting standards. Morphometric analysis of the foramen magnum dimensions across all study cohorts demonstrated no statistically significant differences ($p > 0.05$). Specifically, the mean transverse diameter of the foramen magnum was 22.0 ± 5.6 mm in individuals without a CC, 23.0 ± 4.6 mm in the unilateral CC group, and 24.0 ± 4.6 mm in the bilateral CC group. Similarly, the mean sagittal diameter of the foramen magnum was 18.3 ± 6.0 mm in individuals with an absent CC, 19.6 ± 7.4 mm in those with a unilateral CC, and 20.0 ± 8.5 mm in patients with a bilateral CC. No statistically significant differences were detected among the groups in these transverse and sagittal anatomical measurements ($p > 0.05$).¹²

In our study, both anteroposterior and transverse diameters were measured. In cases with bilateral CCs, the mean transverse diameter was 3.57 ± 0.71 mm, the mean anteroposterior diameter was 2.67 ± 0.97 mm on the right and 2.47 ± 1.05 mm on the left, and the mean distance between the two canals was 41.9 ± 11.5 mm. In cases with a unilateral CC, the mean transverse diameter was 3.07 ± 0.84 mm, whereas the mean anteroposterior diameter was 2.26 ± 0.86 mm. The CC measurements obtained in our study were comparable to those reported in the literature. Our study provides additional morphometric data on the anteroposterior and transverse dimensions of the CC.

Limitations

This study has several limitations. First, its retrospective design may have limited the accuracy and completeness of the clinical data obtained from patient records. Second, although the overall sample size was mathematically adequate, the low frequency of specific clinical symptoms within the subgroups may have reduced the statistical power to detect subtle associations, thereby increasing the risk of type II errors. Additionally, imaging was performed using 3-mm CT slices, which may have limited the detailed evaluation of small anatomical structures. The absence of advanced

imaging modalities, such as MR venography, also limited the assessment of functional venous drainage. Finally, this was a single-center study, which may limit the generalizability of the findings to broader populations. Future multicenter studies with larger cohorts and multimodal imaging techniques are warranted to validate and expand upon our findings.

CONCLUSION

In conclusion, our findings demonstrate that the condylar canal (CC) exhibits considerable normal anatomical variability, presenting as bilateral, unilateral, or completely absent configurations across the study population. Within the methodological limitations of this retrospective, single-center study, no statistically significant correlations were detected between specific CC variants and clinical or demographic parameters in this particular sample. Although the overall sample size provided adequate statistical power, the low frequency of specific clinical symptoms across the cohorts increased the risk of type II errors, whereby subtle clinical associations may have remained undetected. Therefore, these descriptive findings should be interpreted as indicating a lack of detectable statistical correlation within the current sample rather than definitive evidence of clinical irrelevance. Recognition of these morphometric variations remains essential in neurosurgical planning and radiological evaluation to prevent inadvertent vascular and hemorrhagic complications during skull base interventions. Future prospective, multicenter studies using advanced multimodal imaging techniques and larger patient cohorts are warranted to further evaluate and validate the potential clinical relevance of these anatomical variations.

Ethics Committee Approval: Ethics committee approval was obtained from Malatya Turgut Özal University Non-Interventional Clinical Research Ethics Committee (Approval Number: 2022/136, Date: 05.09.2022).

Informed Consent: Written informed consent was not required due to the retrospective nature of this study.

Conflict of Interest: The authors have no conflicts of interest to declare.

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