



Evaluation of the Prevalence of Mandibular Canal Variations Using Cone-beam Computed Tomography

Mandibular Kanal Varyasyon Prevalansının Konik Işınlı Bilgisayarlı Tomografi ile Değerlendirilmesi

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ABSTRACT

Objective: Hidden anatomical variations of the mandibular canal may substantially increase the risk of hemorrhage, neurosensory injury, and surgical complications during implant placement, third molar surgery, and other invasive procedures. Despite their clinical relevance, these variations are frequently overlooked on routine imaging. This study aimed to determine the prevalence and distribution of mandibular canal variations using cone-beam computed tomography (CBCT) and to evaluate their associations with age, sex, edentulism, and laterality.

Methods: In this retrospective cross-sectional study, 794 hemi-mandibular CBCT images from 426 patients (286 females, 140 males; mean age: 43.68±12.34 years) were analyzed. Variations were classified according to the Naitoh system. Associations were assessed using Pearson's chi-square test ($p<0.05$).

Results: Mandibular canal variations were identified in 86.4% of hemi-mandibles. The most prevalent subtype was Type 3 (retromolar canal) (46.2%), followed by Type 2 (dental canal) (28.7%). No significant association was found with sex ($p=0.123$) or side distribution ($p=0.120$). Significant associations were observed with age ($p=0.001$), with Type 3 variations predominating in the 41-50 years group, and with edentulism status ($p=0.001$), particularly in individuals with posterior molar tooth loss.

Conclusion: Mandibular canal variations are highly prevalent and should be regarded as clinically relevant rather than incidental findings. The retromolar canal was the dominant

ÖZ

Amaç: Mandibular kanalın gizli anatomik varyasyonları, implant yerleştirilmesi, üçüncü molar cerrahisi ve diğer invaziv işlemler sırasında hemoraji, nörosensoriyel yaralanma ve cerrahi komplikasyon riskini belirgin şekilde artırabilir. Klinik önemlerine rağmen bu varyasyonlar rutin görüntülemelerde sıklıkla gözden kaçmaktadır. Bu çalışmanın amacı, konik ışınlı bilgisayarlı tomografi (KİBT) ile mandibular kanal varyasyonlarının prevalansını ve dağılımını belirlemek; ayrıca yaş, cinsiyet, dişsizlik durumu ve taraf ile ilişkilerini değerlendirmektir.

Yöntemler: Bu retrospektif kesitsel çalışmada, 426 hastaya ait 794 hemimandibular KİBT görüntüsü (286 kadın, 140 erkek; ortalama yaş: 43,68±12,34 yıl) incelendi. Varyasyonlar Naitoh sınıflamasına göre değerlendirildi. İlişkiler Pearson ki-kare testi ile analiz edildi ($p<0,05$).

Bulgular: Mandibular kanal varyasyonları hemimandibuların %86,4'ünde saptandı. En sık görülen alt tip Tip 3 (retromolar kanal) (%46,2) olup, bunu Tip 2 (dental kanal) (%28,7) izledi. Cinsiyet ($p=0,123$) ve taraf dağılımı ($p=0,120$) ile anlamlı ilişki bulunmadı. Yaş ile anlamlı ilişki saptandı ($p=0,001$); Tip 3 varyasyonlar en sık 41-50 yaş grubunda görüldü. Ayrıca dişsizlik durumu ile de anlamlı ilişki bulundu ($p=0,001$), özellikle posterior molar diş kaybı olan bireylerde daha belirgindi.

Sonuç: Mandibular kanal varyasyonları oldukça yaygın olup tesadüfi bulgular olarak değil, klinik açıdan önemli anatomik oluşumlar olarak değerlendirilmelidir. Retromolar kanal baskın alt tip olarak belirlenirken, yaş ve dişsizlik varyasyon

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ABSTRACT

subtype, while age and edentulism significantly influenced variation patterns. Preoperative CBCT assessment is strongly recommended to optimize treatment planning and minimize neurovascular complications.

Keywords: Mandibular canal variations, CBCT, retromolar canal, Naitoh classification

Öz

paternlerini anlamlı şekilde etkilemiştir. Tedavi planlamasını optimize etmek ve nörovasküler komplikasyonları azaltmak için işlem öncesi KIBT değerlendirmesi şiddetle önerilmektedir.

Anahtar Kelimeler: Mandibular kanal varyasyonları, KIBT, retromolar kanal, Naitoh sınıflaması

Introduction

The mandibular canal is defined as a bilateral vascular-neural structure that begins at the mandibular foramen, curves downward and forward beneath the roots of the molar teeth, and terminates at the mental foramen (1). This canal contains the inferior alveolar nerve, inferior alveolar artery, and inferior alveolar vein. It plays a critical role in the functional and anatomical integrity of the mandible (2,3). The location and structure of the mandibular canal are important for endodontic treatment, impacted third molar extraction, dental implant applications, and orthognathic surgery involving the mandible (4-6).

Anatomical variations of the mandibular canal can present a wide range. Variations frequently reported in the literature include bifid mandibular canals, where the canal follows a double path, as well as retromolar canals, forward canals, dental canals, and buccolingual canals (7,8). Accurate identification of the localization of mandibular canal variations not only protects the patient from various surgical complications but also facilitates the clinician's work. These anatomical variations should be examined in detail to reduce the risk of nerve damage and prevent complications (9-12).

In recent years, advancements in dental imaging technologies have made it possible to examine the mandibular canal in greater detail. Conventional radiographic methods provide only two-dimensional imaging of the mandibular canal, making it insufficient to adequately assess depth information or variations (3,13). In contrast, cone-beam computed tomography (CBCT) has become a crucial tool for the detailed evaluation of dental and maxillofacial structures, allowing for three-dimensional and high-resolution imaging of the mandibular canal (10,14,15). The detailed images provided by CBCT enable high-resolution three-dimensional visualization of the mandibular canal and offer significant advantages in detecting canal variations and determining their prevalence (9,11,16).

This study aims to investigate the variations of the mandibular canal using CBCT and evaluate their prevalence. By addressing gaps in the literature and aiming to better understand the clinical significance of mandibular canal

anatomy, this study seeks to provide important insights to guide surgical and dental treatment planning.

Methods**Study Design and Ethical Approval**

This retrospective cross-sectional investigation was approved by the Non-Interventional Ethics Committee of Bezmialem Vakıf University (approval no: E-54022451-050.05.04-108546, decision no: 2023/177, date: 26.05.2023). All study procedures complied with the ethical principles of the Declaration of Helsinki.

Study Population and Sample Selection

This cross-sectional retrospective study utilized CBCT images obtained from patients who attended Bezmialem Vakıf University, Faculty of Dentistry, Department of Oral and Maxillofacial Radiology between September 2022 and December 2022. Images had been acquired for various diagnostic and treatment-planning purposes, including impacted tooth evaluation, implant planning, orthodontic assessment, and orthognathic surgical planning.

All available CBCT scans meeting the inclusion criteria during the study period were screened, aiming to reflect the study population routinely referred for CBCT examination. Inclusion criteria required high-quality CBCT images that fully demonstrated the mandibular canal entrance and course. Exclusion criteria included congenital anomalies or severe jaw deformities, maxillofacial fractures, neoplasms, intraosseous lesions affecting the mandibular canal, and scans degraded by motion or imaging artifacts.

A total of 965 patients' CBCT images were screened. After applying the inclusion and exclusion criteria, CBCT images of 58 patients with unilateral scans and 368 patients with bilateral scans, resulting in a total of 794 CBCT images from 426 patients, were included in the study.

CBCT Acquisition Parameters

All scans were obtained using the Planmeca ProMax 3D Mid Proface unit (Finland) under high-resolution settings (90 kVp, 10 mA, exposure time: 18-36 s; voxel size: 0.2 mm³). Image datasets were reconstructed using Romexis software (version 3.8.3.R) and exported in DICOM format for evaluation.

Image Evaluation and Observer Reliability

All CBCT images were independently evaluated by two dentomaxillofacial radiologists with 3 years (NG) and 4 years (NK) of experience. In cases of disagreement, the images were re-evaluated jointly and a final consensus decision was reached. Observer agreement was assessed using weighted kappa statistics. Inter-observer agreement was calculated based on the initial independent evaluations, and the agreement between each observer's initial assessment and the final consensus evaluation was also analyzed.

Image Reconstruction and Assessment Procedure

Cross-sectional and panoramic images were reconstructed for all hemi-mandibles based on axial sections. Evaluations were performed on cross-sectional slices with a 0.5 mm slice interval. For each hemi-mandibular canal, reconstructed panoramic views and buccolingual cross-sectional slices were created and analyzed using Romexis version 3.8.3.R software.

Panoramic views were reconstructed based on an oblique line drawn through the center of each root on an axial section passing through the cervical regions of the teeth. Perpendicular to this oblique line, 0.5 mm thick buccolingual cross-sectional slices were prepared.

Classification of Mandibular Canal Variations

The prevalence of mandibular canal variations was determined according to the Naitoh classification (16). This classification is categorized as follows (Figure 1):

Type 1 Forward canal

A: Intersecting

B: Non-intersecting

Type 2 Dental canal

C: Branch reaching the first molar

D: Branch reaching the second molar

E: Branch reaching the third molar

Type 3 Retromolar canal

F: Retromolar canal

Type 4 Buccolingual canal

G: Branch diverging from the buccal wall of the main canal

H: Branch diverging from the lingual wall of the main canal.

Outcome Measures

In each hemi-mandible, the prevalence and type of mandibular canal variation were evaluated. The correlations between variation types and age groups, gender, edentulism status, and orientation were also assessed.

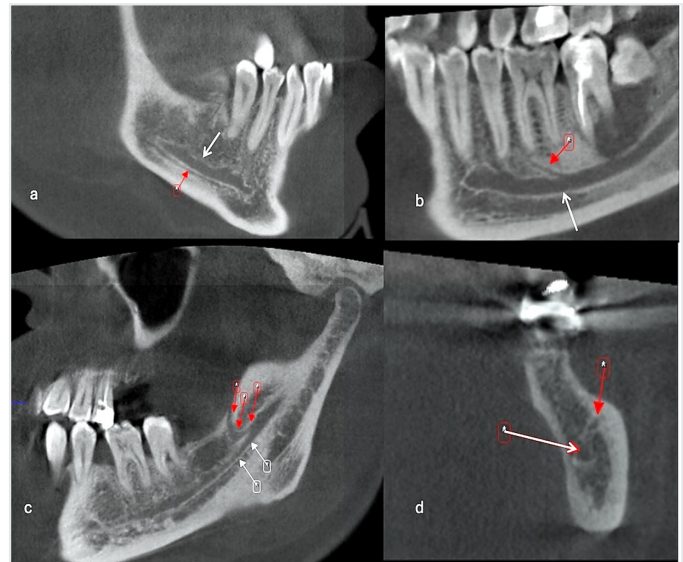


Figure 1. Representative CBCT images demonstrating mandibular canal variations according to the Naitoh classification. (a) Type 1 forward canal (intersecting): accessory canal arising from the main mandibular canal and coursing anteriorly with intersection. (b) Type 2 dental canal: branch extending toward the first molar region. (c) Type 3 retromolar canal: accessory branch extending superiorly toward the retromolar area posterior to the third molar region. (d) Type 4 buccolingual canal (lingual type): branch diverging from the lingual wall of the main mandibular canal. Red arrows indicate the variation canals, whereas white arrows indicate the main mandibular canal

CBCT: Cone-beam computed tomography

Statistical Analysis

All statistical analyses were performed using SPSS version 28.1 (IBM Corp., Chicago, IL, USA). Descriptive variables were summarized as mean, standard deviation, minimum, maximum, frequency, and percentage where appropriate. Associations between categorical variables were tested using Pearson's chi-square test. To account for the potential correlation between the right and left hemi-mandibles within the same individual, an additional analysis was performed using generalized estimating equations (GEE). Weighted kappa coefficients were used to determine observer agreement. A p-value below 0.05 was considered statistically significant.

Results

Study Population Characteristics

A total of 794 hemi-mandibular CBCT images obtained from 426 patients were included in the study. The mean age of the study population was 43.68 ± 12.34 years (range: 10-77 years). Of the evaluated hemi-mandibles, 67.1% (n=533) belonged to female participants and 32.9% (n=261) to male participants. No missing data were present in the final analysis.

Regarding age distribution, the largest proportion of participants was in the 41-50 years age group (25.9%), followed by the 31-40 years group (19.8%). In terms of dentition status, 32.9% of participants had no molar tooth loss, whereas 21.4% had two missing molars. Side distribution showed a slight predominance of the right side (51.5%). Detailed demographic and clinical characteristics are presented in Table 1.

Prevalence and Distribution of Mandibular Canal Variations

Mandibular canal variations were identified in 86.4% of the evaluated hemi-mandibles. The most common variation type was Type 3 (retromolar canal) (46.2%), followed by Type 2 (dental canal) (28.7%). No variation was observed in 13.6% of cases. Detailed distributions of variation types and subtypes are presented in Tables 2 and 3.

Association Between Mandibular Canal Variations and Sex or Side

No statistically significant association was found between sex and mandibular canal variations (χ^2 test, $p=0.123$), indicating a similar distribution between males and females. Likewise, no significant difference was observed

between the right and left sides (χ^2 test, $p=0.120$). When the potential correlation between the right and left hemi-mandibles of the same individual was taken into account using a GEE model, no significant association was observed between side and Naitoh classification ($p=0.364$).

Association Between Mandibular Canal Variations and Age Group

A statistically significant association was identified between age group and mandibular canal variations (χ^2 test, $p=0.001$). Type 3 variations were more frequently observed in the 41-50 years age group. Detailed comparisons are presented in Table 2.

Association Between Mandibular Canal Variations and Edentulism Status

Edentulism status was also significantly associated with mandibular canal variations (χ^2 test, $p=0.001$). Type 3 variation was observed in 19.9% ($n=57$) of individuals with one missing molar and 21.4% ($n=100$) of those with two missing molars. Detailed comparative analyses are presented in Table 2.

Observer Agreement

Observer agreement results are summarized in Table 4.

Discussion

Identification of anatomical variations of the mandibular canal is of vital importance in dental surgery and implantology procedures. In the present study, the prevalence and types of mandibular canal variations were evaluated and the findings were compared with the current literature.

In our study, mandibular canal variations were detected in 86.4% of the 794 hemi-mandibular images examined. This rate is higher than those reported in previous studies. Doğan and Kotanlı (17), reported a prevalence of 66.1% for mandibular canal variations in a Turkish population using CBCT. Similarly, Orhan et al. (18), in their study evaluating root canal morphology of the lower anterior teeth using CBCT, reported a prevalence of 55.6% for mandibular canal variations. Özarslantürk and Avsever (19), on the other hand, found a variation rate of 8.57% in CBCT images of a Turkish population. In a systematic review conducted by Samieirad et al. (20), the overall prevalence of bifid mandibular canal was reported as 18%; however, this rate increased to 25% in studies evaluated using CBCT. The differences observed between the present study and the literature may be attributed to variations in sample size, population characteristics, and imaging techniques used among studies. The relatively high prevalence observed in the present study may also be related to methodological factors. The use of CBCT images acquired with a 0.2-mm voxel size may have facilitated the detection of small accessory canals and subtle anatomical variations that

		Frequency (n)	Percent (%)
Gender	Female	533	67.1
	Male	261	32.9
Age groups	10-20 years	68	8.6
	21-30 years	94	11.8
	31-40 years	157	19.8
	41-50 years	206	25.9
	51-60 years	155	19.5
	61-70 years	96	12.1
	71-80 years	18	2.3
	No variation	108	13.6
Classification of variations	Type 1	23	2.9
	Type 2	228	28.7
	Type 3	367	46.2
	Type 4	68	8.6
	Total edentulism	60	7.6
	No molar missing	261	32.9
Classification of edentulism	One missing molar	158	19.9
	Two missing molars	170	21.4
	Three missing molars	145	18.3
Side of assessment	Right side	409	51.5
	Left side	385	48.5

Table 2. The relationship of classifications of variations with gender, age groups, dentition status, and sides

		Classification of variations					p-value
		No variation	Type 1	Type 2	Type 3	Type 4	
Gender	Female	78	15	140	258	42	0.123
	Male	30	8	88	109	26	
Age groups	10-20 years	10	0	47	10	1	0.001*
	21-30 years	7	2	50	31	4	
	31-40 years	18	5	57	62	15	
	41-50 years	26	8	48	99	25	
	51-60 years	24	3	20	91	17	
	61-70 years	20	5	4	62	5	
	71-80 years	3	0	2	12	1	
Classification of edentulism	Total edentulism	0	3	0	50	7	0.001*
	No molar missing	108	1	108	36	8	
	One missing molar	0	9	80	57	12	
	Two missing molars	0	5	40	100	25	
Side of assessment	Three missing molars	0	5	0	124	16	0.120
	Right side	43	11	124	196	35	
	Left side	65	12	104	171	33	

*: p<0.05, Pearson chi-square

Table 3. Distribution of mandibular canal variation subtypes according to the Naitoh classification

Naitoh subtype	Description	n	%
Type 1A	Intersecting forward canal	5	0.7
Type 1B	Non-intersecting forward canal	18	2.6
Type 2C	Branch reaching the first molar	32	4.7
Type 2D	Branch reaching the second molar	77	11.2
Type 2E	Branch reaching the third molar	119	17.3
Type 3F	Retromolar canal	367	53.5
Type 4G	Branch diverging from the buccal wall of the main canal	60	8.7
Type 4H	Branch diverging from the lingual wall of the main canal	8	1.2
Total		686	100.0

Percentages were calculated based on the total number of detected mandibular canal variations (n=686)

might be overlooked at larger voxel sizes. In addition, the use of a consensus-based final evaluation may have reduced the likelihood of missed findings and contributed to the identification of a greater number of mandibular canal variations. Therefore, differences in prevalence rates among studies should be interpreted not only in terms of population characteristics but also with consideration of imaging parameters and assessment protocols.

In the present study, the most frequently observed mandibular canal variation was Type 3 (retromolar canal), with a prevalence of 46.2%. This finding partially differs from some previously published studies. Naitoh et al. (16) reported that the most common mandibular canal variation was the anterior canal type (55.3%). In contrast, Kang et al. (21) found that the retromolar canal was the most

common variation type (52.5%) in a Korean population. Özarıslantürk and Avsever (19) also reported that the retromolar canal was the most frequently observed variation (63.7%). However, studies reporting lower frequencies are also available. Bilecenoglu and Tuncer (22) identified retromolar canals in 25% of their Turkish sample, whereas the lowest prevalence was reported by Kuribayashi et al. (15), who detected retromolar canals in only 1.7% of 252 patients evaluated with CBCT. In a CBCT-based study conducted in the Çukurova subpopulation, Tumanı et al. (23) reported the anterior canal as the most common variation type (31.4%), followed by the dental canal (29.7%), retromolar canal (26.3%), and buccolingual canal (12.7%). These findings differ from the results of the present study, in which the retromolar canal was the predominant variation type. These differences in

reported prevalence rates suggest that mandibular canal morphology may vary among populations. Among the evaluated subtypes, Type 3F (retromolar canal) was the most prevalent subtype, whereas Type 1A (intersecting forward canal) and Type 4H (lingual buccolingual canal) were the least prevalent subtypes. Within the dental canal group, Type 2E (branch reaching the third molar) was observed more frequently than Type 2D and Type 2C. Similarly, Özarslantürk and Avsever (19) found retromolar canal-related variations to be the most common (63.7%), followed by dental canal variations (30%), whereas forward canal variations accounted for only 5% of cases. In contrast, Orhan et al. (9) reported the forward canal as the most common variation type (20.4%), with non-intersecting forward canals (13.8%) more frequent than intersecting ones. Retromolar canals were observed in 20% of cases, while dental canals were less common overall (4.4%), with the third molar branch (2.7%) representing the most common dental subtype. Buccolingual canals were found in 8.8% of cases, with buccal branches (5.7%) slightly more frequent than lingual branches (3.1%). These differences in subtype distribution may reflect methodological and population-related variations.

In the present study, no statistically significant difference was found between sexes regarding the distribution of mandibular canal variations. This finding is consistent with several previous studies reported in the literature. Orhan et al. (9), in a CBCT-based study conducted in a Turkish population, detected mandibular canal variations in 46.5% of 242 patients and reported that these variations did not differ significantly between males and females. Similarly, Özarslantürk and Avsever (19) also reported that mandibular canal variations were not associated with sex. Similarly, Tumani et al. (23) also found no significant association between bifid mandibular canal distribution and sex. However, in a systematic review and meta-analysis conducted by Asghar et al. (24), mandibular canal variations were reported to be 25% more prevalent in males than in females. Taken together, these findings suggest that the influence of sex on mandibular canal variations remains inconclusive, and further large-scale studies are warranted.

When the relationship between age groups and mandibular canal variations was evaluated in the present study, Type 3 variation was found to be significantly more frequent in the 41-50 years age group ($p=0.001$). Although this

finding indicates a potential association between age and mandibular canal variations, the independent effect of age cannot be determined because potential confounding factors, such as edentulism and dental status, were not controlled for in the analysis. Studies investigating the effect of age on mandibular canal variations are limited. Özarslantürk and Avsever (19) reported no significant differences among age groups. Likewise, in the comprehensive systematic review and meta-analysis by Asghar et al. (24), no statistically significant association was found between age and the prevalence of mandibular canal variations. Further studies incorporating multivariable analyses and larger populations are needed to clarify the relationship between age and mandibular canal variations.

In the present study, when the relationship between edentulism and mandibular canal variations was evaluated, the frequency of Type 3 variation was found to be significantly increased particularly in individuals with the absence of one or two molar teeth. This finding indicates a possible association between posterior tooth loss and mandibular canal variations; however, the underlying mechanism remains unclear. Similarly, Bilecenoglu and Tuncer (22) reported that alveolar resorption resulting from edentulism may alter the course of the canal and render existing variations more radiographically apparent. Therefore, careful evaluation of mandibular canal variations before surgical procedures is particularly important in patients with posterior tooth loss. Von Arx and Bornstein (13) also suggested that the increased radiographic visibility of tubular structures with age or edentulism may not necessarily reflect true anatomical changes.

Regarding side-related (right/left) distribution of variations, no statistically significant difference was observed in the present study. Similar findings were reported by Tumani et al. (23) and Özarslantürk and Avsever (19), both of whom found no significant differences between the right and left sides. In contrast, in the systematic review and meta-analysis conducted by Asghar et al. (24), the likelihood of detecting mandibular canal variations on the right side was reported to be 21% higher than on the left side. In the same study, unilateral bifid mandibular canal variations were reported to occur approximately three times more frequently than bilateral variations. Further studies are needed to clarify the potential influence of side on mandibular canal variations.

Table 4. Observer agreement for mandibular canal variation classification			
Comparison	Weighted kappa	95% CI	Interpretation
Observer 1 vs. observer 2	0.838	(0.796-0.883)	Very good
Observer 1 vs. final consensus	0.919	(0.881-0.952)	Excellent
Observer 2 vs. final consensus	0.894	(0.864-0.932)	Very good
0.81-1.00 almost perfect (25) CI: Confidence interval			

Study Limitations

Several limitations of this study should be considered when interpreting the findings. First, due to the retrospective cross-sectional design, causal relationships cannot be established. The results only demonstrate associations between the evaluated variables and do not permit cause-and-effect inferences.

Second, although a relatively large sample was evaluated, the study was conducted at a single center and within a Turkish population. Therefore, the generalizability of the findings to other ethnic or geographic populations may be limited.

Third, unilateral and bilateral hemi-mandibles were analyzed as separate observational units. Although this approach increased the sample size, potential correlations between the right and left sides of the same individual may have affected the statistical independence of the observations.

Fourth, mandibular canal variations were classified according to the Naitoh classification system. Although this system is widely used, certain anatomical variations that do not fully conform to these predefined categories may have been overlooked or simplified.

Finally, potential confounding factors such as dental history, degree of alveolar bone resorption, systemic diseases, and craniofacial morphological characteristics were not assessed. Future multicenter prospective studies with standardized protocols and more comprehensive clinical variables would be valuable.

Additionally, one limitation is that the data were acquired from a single CBCT device. The use of one imaging system may introduce potential biases in detection or measurement of variations. Future studies involving multiple imaging devices may provide broader applicability.

Conclusion

This study demonstrated a high prevalence of mandibular canal variations, with Type 3 being the most frequently observed subtype. These findings indicate that mandibular canal anatomy exhibits considerable variability and that such variations should be carefully assessed during clinical evaluation and treatment planning.

Although no significant association was found with sex or side distribution, significant relationships were identified with age and edentulism status. Type 3 variation was more frequently observed in individuals aged 41-50 years and in patients with posterior molar tooth loss.

Therefore, detailed anatomical assessment using CBCT before implant placement, third molar surgery, and other invasive mandibular procedures may contribute to minimizing potential neurovascular complications and improving treatment planning.

Ethics

Ethics Committee Approval: This retrospective cross-sectional investigation was approved by the Non-Interventional Ethics Committee of Bezmiâlem Vakıf University (approval no: E-54022451-050.05.04-108546, decision no: 2023/177, date: 26.05.2023).

Informed Consent: Retrospective study.

Declaration on the Use of Artificial Intelligence (AI)

For transparency, the authors note that an artificial intelligence-assisted language model was utilized solely for language correction. This assistance was limited to linguistic refinement; all scientific content, critical analysis, and final editorial decisions were made exclusively by the authors.

Footnotes

Authorship Contributions

Concept: E.A., N.K., N.G., Design: E.A., İ.S., Data Collection or Processing: E.A., N.K., N.G., Analysis or Interpretation: E.A., N.K., N.G., İ.S., Literature Search: E.A., N.K., N.G., İ.S., Writing: E.A., N.K., N.G., İ.S.

Conflict of Interest: No conflict of interest was declared by the authors.

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