Cukurova Medical Journal
ÇUKUROVA ÜNİVERSİTESİ TIP FAKÜLTESİ

Cukurova Med J 2026;51(2):559-566
DOI: 10.17826/cumj.1911392

RESEARCH

Influence of mastoid pneumatization degree on the facial canal position within the skull base in pediatric population: a computed tomography study

Pediatrik popülasyonda mastoid pnömatizasyon derecesinin fasiyal kanalın kafa tabanındaki konumuna etkisi: bir bilgisayarlı tomografi çalışması

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Abstract

Purpose: This study aimed to evaluate the developmental pattern of mastoid pneumatization in the pediatric population and to investigate its relationship with the anatomical positioning of the mastoid segment of the facial canal.

Materials and Methods: Computed tomography images of patients were retrospectively analyzed. Pneumatization degree was classified into four categories: The hypopneumatization, moderate, good, and hyperpneumatization. Measurements of the facial canal, including its distance to the external acoustic meatus, sigmoid sinus, posterior cranial fossa and mastoid surface, were obtained by two independent observers.

Results: A total of 197 children (91 males,106 females; mean age 6.31±5.36 years) were included. Pneumatization degree differed significantly across age groups, with hypopneumatization most commonly observed in the infancy period and increasing progressively until the post-pubescent stage. Measurements of the facial canal varied significantly across pneumatization categories: The distance between the canal and the mastoid surface was greatest in the hyperpneumatized group (14.34±2.91 mm), whereas the canal sigmoid sinus distance was significantly larger (10.77±2.66 mm) in moderately pneumatized bones.

Conclusion: Mastoid pneumatization demonstrates a clear age-dependent progression throughout childhood and adolescence, and the degree of pneumatization significantly influences the spatial relationships of the mastoid segment of the facial canal.

Keywords: Computed tomography, facial canal, mastoid pneumatization, mastoid segment, temporal bone

Öz

Amaç: Bu çalışmanın amacı pediatrik popülasyonda mastoid pnömatizasyonun gelişimsel paternini değerlendirmek ve bunun canalis facialis'in mastoid segmentinin anatomik yerleşimi ile ilişkisini araştırmaktır.

Gereç ve Yöntem: Hastaların bilgisayarlı tomografi görüntüleri retrospektif olarak analiz edildi. Pnömatizasyon derecesi dört kategoriye ayrıldı: Hipopnömatizasyon, orta derecede pnömatizasyon, iyi pnömatizasyon ve hiperpnömatizasyon. Canalis facialis ölçümleri; meatus acusticus externus, sinus sigmoideus, fossa cranii posterior ve mastoid yüzeye olan mesafeleri kapsayacak şekilde iki bağımsız gözlemci tarafından elde edildi..

Bulgular: Toplam 197 çocuk (91 erkek, 106 kız; ortalama yaş 6.31±5.36 yıl) çalışmaya dahil edildi. Pnömatizasyon derecesi yaş grupları arasında anlamlı farklılık gösterdi; hipopnömatizasyon en sık infantil dönemde gözlenirken postpubertal döneme kadar kademeli olarak artış gösterdi. Canalis facialis ölçümleri pnömatizasyon kategorilerine göre anlamlı farklılık gösterdi: Kanal ile mastoid yüzey arasındaki mesafe hiperpnömatize grupta en yüksek iken (14,34±2,91 mm), kanal ile sigmoid sinüs arasındaki mesafe orta derecede pnömatize kemiklerde (10,77±2,66 mm) anlamlı derecede daha büyüktü.

Sonuç: Mastoid pnömatizasyon çocukluk ve adölesan dönem boyunca yaşa bağlı belirgin bir progresyon göstermektedir ve pnömatizasyon derecesi canalis facialis'in mastoid segmentinin konumunu anlamlı şekilde etkilemektedir.

Anahtar kelimeler: Basis cranii, bilgisayarlı tomografi, canalis facialis, mastoid pnömatizasyon, mastoid segment

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Received: 17.03.2026 Accepted: 27.05.2026

INTRODUCTION

The temporal bone (TB) comprises three main parts: Squamous, petrous, and tympanic parts. It also includes two main processes, as mastoid and styloid processes. TB develops primarily through mastoid pneumatization[1]. Pneumatization has been reported to be visible from the 24th week of gestation[1-3]. Complete pneumatization of bone is completed in three stages: Newborn–2 years, 2–5 years, and adulthood: Air cells begin to become apparent in infancy. During the transitional period (2–5 years), the squamomastoid region expands by the migration of air cells to the surrounding area, and the pneumatization process ends when adulthood is reached[1].

Despite its relatively small size, TB includes the middle and internal ear components, multiple cranial nerves, and key vascular structures within a tightly limited space[4]. This anatomical complexity makes the interpretation of imaging findings and the diagnosis of TB pathologies challenging[5,6]. The position, dimensions, and shape of critical structures such as the facial canal (FC) and the sigmoid sinus (SS) vary considerably between individuals and even between sides[4,7]. It has been suggested that such variability may be largely attributable to differences in TB pneumatization[5,6].

Facial nerve's intratemporal part is closely associated with the tympanic cavity[8]. In particular, facial nerve's mastoid segment is vulnerable to injury during surgical procedures involving the tympanic cavity[9-11]. FC begins with the facial nerve's course toward anterosuperior portion of the fundus of internal acustic meatus. The facial nerve mastoid segment continues from the second genu to styloid foramen. Due to mastoid pneumatization, the mastoid segment of FC can be easily identified on axial computed tomography (CT) and magnetic resonance imaging scans. Excessive pneumatization has been reported to complicate CT evaluation[12-14].

In children, mastoid procedures are performed for indications including acute mastoiditis, cholesteatoma, and cochlear implantation for congenital sensorineural hearing impairment. Nevertheless, the structure of the mastoid in pediatric patients shows marked morphological differences compared with that of adults[8]. The absence of a well-developed mastoid process in infants renders the facial nerve more superficial particularly at the stylomastoid foramen level and therefore more vulnerable. The frequency of facial nerve injury is approximately 1% in main otologic surgery, but increases to 4–10% in revision procedures[9]. It remains superficially located until mastoid process development is largely completed between 1 and 3 years of age. With the expansion of tympanic ring, facial nerve moves further medially, and gains additional protection[15]. It has been noted that facial nerve's mastoid portion is the last segment to achieve its fully developed anatomy, reaching adult size approximately between 7 and 9 years of age[16-19]. Thus, detailed knowledge of mastoid pneumatization and its relationship to adjacent structures is essential for diminishing risk of iatrogenic facial nerve injury.

Although several studies have evaluated the anatomy of the facial canal, data regarding the positional relationship between the mastoid segment of the facial canal and mastoid pneumatization in the pediatric population remain limited. Understanding this relationship is particularly important for surgical procedures such as posterior tympanotomy and cochlear implantation. Therefore, the present study aims to provide a detailed morphometric evaluation of the distances between the mastoid segment of the facial canal and adjacent skull base structures in children, and to investigate their relationship with the degree of mastoid pneumatization, thereby contributing novel data to the limited pediatric literature. We hypothesized that the degree of mastoid pneumatization significantly affects the spatial relationship between the mastoid segment of the facial canal and surrounding anatomical landmarks.

MATERIALS AND METHODS

Study design

The study was conducted at the Department of Anatomy of Gaziantep University in collaboration with the Department of Otorhinolaryngology Head and Neck Surgery at Gaziantep City Hospital. This retrospective study was based on computed tomography (CT) images that had been routinely acquired for diagnostic purposes and were retrieved from the institutional archive. All imaging data were evaluated in accordance with institutional protocols to ensure data reliability and standardization. The procedures and measurements were performed by experienced otorhinolaryngology surgeon (*SG*) and anatomists (*SSA, AEK, PK*).

Ethical approval was obtained from the Gaziantep University Non-Interventional Clinical Research Ethics Committee (Approval no: 2024/243; dated 31.07.2024).

Sample

A power analysis was performed for the study with a significance level of $\alpha = 0.05$ and a statistical power of $1-\beta = 0.80$, which indicated a minimum required sample size of 150. Given the sample sizes reported in the literature, a total of 250 images were retrospectively examined within the scope of the study.

This study included computed tomography (CT) scans of pediatric patients (up to 18 years) who applied to the ear, nose, and throat department of Gaziantep City Hospital between March 2024 and March 2025, and who had cranial CT scans performed for any reason were included in the study. Cases were excluded if CT scans were compromised by motion artifacts, lacked thin-slice sections, or if patients presented with acquired or congenital abnormalities of TB; accordingly, 53 images were excluded from the study.

CT images acquisition

All CT scans have been performed using a 128-slice multidetector CT scanner (Incisive; Philips Medical Systems, Cleveland, OH, USA). The scan parameters included 120 kVp tube voltage and automatic tube current modulation (200–300 mAs). Images were acquired in helical mode with a collimation of 128 × 0.625 mm. Thin-section images (0.625 mm slice thickness) were reconstructed in the axial plane and reformatted in sagittal and coronal planes using multiplanar reformation.

Radiologic evaluation of CT images

DICOM-formatted CT images were imported into Radiant DICOM Viewer (version 2025.1; Poznań, Poland) for analysis. To assess interobserver reliability, 20% of the CT images were independently re-evaluated by a second observer (an otorhinolaryngologist, SG) for both pneumatization grading and validation of morphometric measurements. The initial evaluations were performed by an anatomist.

Classification of mastoid pneumatization

The extent of TB pneumatization was classified into 4 groups based on its relationship to sigmoid sinus (SS) [20].

1. Hypopneumatization, group 1; aeration was confined to the region medial and anterior to the line drawn through the most anterior margin of SS.
2. Moderate pneumatization group 2; air-cell development reached the area between two imaginary lines traced at the most anterior and the most lateral points of SS.
3. Good pneumatization, group 3; pneumatization spread into the zone located between the lines passing through the lateralmost and posteriormost aspects of SS.
4. Hyperpneumatization, group 4; aeration extended posterolaterally beyond the line intersecting SS at its most posterior point (Figure 1).

Morphometric measurements of facial canal's mastoid segment

For surgical orientation of the facial canal, four reference points were selected: The external acoustic canal anteriorly, the sigmoid sinus posteriorly, the posterior cranial fossa medially, and the most lateral point of the mastoid laterally.

FC-EAC: On axial CT images, the perpendicular distance between FC and a line drawn parallel to the inferior wall of the external auditory canal was measured.

FC-SS: The minimal distance from the FC to SS was assessed on axial CT sections

FC-PCF: The shortest distance separating FC from the posterior cranial fossa was measured on axial CT slices.

FC-M: The horizontal distance between FC and the lateral margin of the mastoid surface was measured on the axial section (Figure 2).

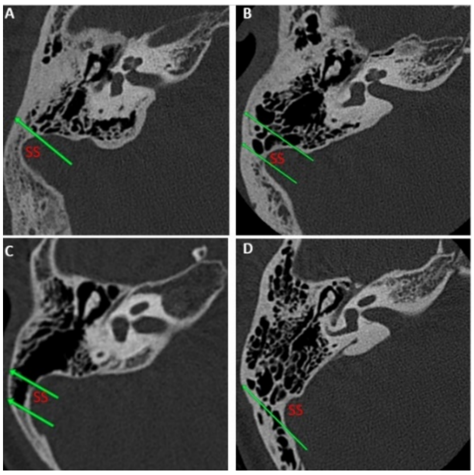

Figure 1. Grouping of pneumatization in relation to the sigmoid sinus.
A) Group 1: Hypopneumatization (the pneumatization remained anteromedial to the line that was drawn at the most anterior point of the sigmoid sinus), B) Group 2: Moderate pneumatization (the pneumatization was extended to the space between the two arbitrary lines drawn at the most anterior point and at the most lateral aspect of the sigmoid sinus), C) Group 3: Good pneumatization (the pneumatization extended to the space between the lines drawn at the most lateral aspect and at the most posterior point of the sigmoid sinus), D) Group 4: Hyperpneumatization (the pneumatization extended posterolaterally beyond the line drawn at the most posterior point of the sigmoid sinus) SS: Sigmoid sinus.

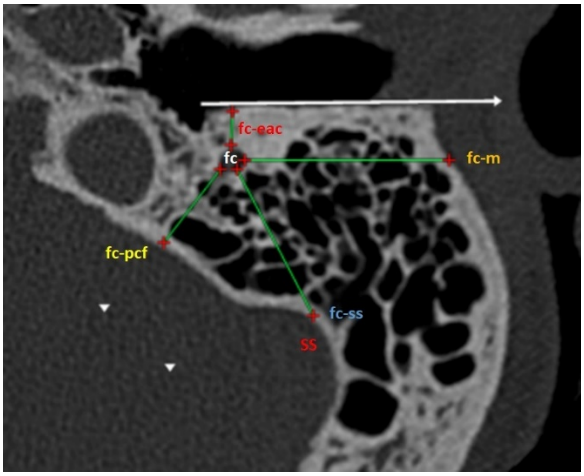

Figure 2. Morphometric measurements of mastoid segment of facial canal.
fc: Mastoid segment of facial canal, SS: Sigmoid sinus, fc-eac: Distance between the facial canal and external acoustic meatus, fc-m: Distance between the facial canal and mastoid surface, fc-ss: Distance between the facial canal and sigmoid sinus, fc-pcf: Distance between the facial canal and posterior cranial fossa.

Statistical analysis

The distribution of data was evaluated for normality using the Shapiro-Wilk test. A Student's t-test was conducted to compare genders, while paired t-tests were employed to assess differences between groups. Inter-observer agreement was analyzed using the intraclass correlation coefficient (ICC). The Kruskal-Wallis H test was utilized to examine differences in measurements across specific age categories. Descriptive statistics were presented as mean ± standard deviation for continuous variables, and frequency and percentage for categorical data. All analyses were performed using SPSS software version 24.0 (IBM Corp., Armonk, NY, USA). A statistical significance level of $p < 0.05$ was considered acceptable.

RESULTS

A total of 197 pediatric subjects 91 boys (mean age: 6.37 ± 5.53 years) and 106 girls (mean age: 6.25 ± 5.24 years) were enrolled in the study. The mean age of the entire cohort was 6.31 ± 5.36 years. There was no statistically significant difference in mean age between male and female participants ($p = 0.878$). Additionally, the measurements obtained by the two observers showed high agreement, with no significant interobserver variability (ICC: 0.936–0.991, $p = 0.001$). The comparison of pneumatization grades by side and gender is presented in Table 1. While pneumatization grade didn't differ between genders ($p=0.449$), a significant difference was observed between sides ($p=0.001$) (Table 1). Overall, Group 1 (*Hypopneumatization*) was the most common pneumatization pattern, followed by Group 2 (*Moderate pneumatization*) and 3 (*Good pneumatization)*, with Group 4 (*Hyperpneumatization*) being the least frequent.

Table 1. Type of pneumatization according to gender and side

Pneumatization degree	Group 1	Group 2	Group 3	Group 4	P
Male (N:182)	47 (25.83)	62 (34.06)	28 (15.38)	45 (24.73)	0.449
Female (N:212)	68 (32.08)	52 (24.52)	24 (11.32)	68 (32.08)	
Right (N:197)	53 (26.90)	70 (35.54)	25 (12.69)	49 (24.87)	*0.001**
Left (N:197)	62 (31.48)	44 (22.34)	27 (13.70)	64 (32.48)	
Total (N:394)	115 (29.18)	114 (28.94)	52 (13.20)	113 (28.68)	

N: Number of side of the temporal bone

Pneumatization grades also differed significantly across age groups (p=0.001). Hypopneumatization was most frequently observed in the infancy period, and the degree of pneumatization increased progressively until the postpubescent stage (Table 2).

Table 2. Distribution of pneumatization by age periods

Age periods	Male	Female	Total	Group 1	Group 2	Group 3	Group 4	P
	N	N	N	N (%)	N (%)	N (%)	N (%)	
Infancy (0-2)	60	66	126	90 (71.42)	26 (20.64)	10 (7.94)	0	***0.001****
Early childhood (3-5)	44	52	96	33 (34.37)	36 (37.50)	20 (20.83)	7 (7.30)	
Late childhood (6-9)	32	46	78	23 (29.49)	35 (44.87)	10 (12.82)	10 (12.82)	
Prepubescent (10-13)	16	16	32	3 (9.37)	10 (31.25)	5 (15.62)	14 (43.76)	
Postpubescent (14-18)	30	32	62	6 (9.68)	12 (19.35)	6 (9.68)	38 (61.29)	
Total	182	212	394	155 (39.34)	119 (30.20)	51 (12.95)	69 (17.51)	

N: Number of side of the temporal bone

Table 3. Comparison of FC distances between genders

Parameters	Gender	N	Mean ± SD (mm)	P
FC-EAC	Male	182	3.85±1.57	0.396
	Female	212	3.69±1.14	
FC-SS	Male	182	10.13±2.58	0.650
	Female	212	9.95±2.90	
FC-PCF	Male	182	6.36±2.12	0.530
	Female	212	6.16±2.38	
FC-M	Male	182	12.55±3.35	0.159
	Female	212	11.96±2.59	

FC-EAC: Distance between the facial canal and external acoustic canal, FC-SS: Distance between the facial canal and sigmoid sinus, FC-PCF: Distance between the facial canal and posterior cranial fossa, FC-M: Distance between the facial canal and mastoid surface, N: Number of side of the temporal bone, SD: Standard deviation

The distances between FC and the anatomical landmarks didn't differ significantly between genders (p>0.05) (Table 3). However, when the measurements were compared across pneumatization groups (hypopneumatization, moderate, good, and hyperpneumatization), significant differences were observed in FC-SS and FC-M (p=0.039, p=0.001, respectively). In the hyperpneumatization group, the FC was located deeper from the mastoid surface, whereas in moderately pneumatized bones, the distance between the sigmoid sinus and the facial canal was significantly greater compared with the other groups (Table 4).

Table 4. Comparison of FC distances according to pneumatization groups

Pneumatization degree	Group 1	Group 2	Group 3	Group 4	P
FC-EAC (mm)	3.93±1.04	3.77±1.89	3.84±1.61	3.58±0.83	0.566
FC-SS (mm)	9.42±3.12	10.77±2.66	9.53±2.31	10.20±2.45	*0.039**
FC-PCF (mm)	5.92±1.94	6.31±2.48	6.82±2.35	6.28±2.27	0.376
FC-M (mm)	10.55±2.07	12.15±2.81	11.61±2.57	14.34±2.91	*0.001**

FC-EAC: Distance between the facial canal and external acoustic canal, FC-SS: Distance between the facial canal and sigmoid sinus, FC-PCF: Distance between the facial canal and posterior cranial fossa, FC-M: Distance between the facial canal and mastoid surface, N: Number of side of the temporal bone, SD: Standard deviation

DISCUSSION

TB pneumatization develops through the transformation of TB into air cells, beginning in the region adjacent to the embryonically formed middle ear cavity and mastoid antrum[1,20]. The genetic theory proposes that the extent of air cell development is predetermined by genetic influences at this stage[21]. Pneumatization of TB is a dynamic developmental process that affects both bone morphology and the location of intratemporal neurovascular structures. In addition, several studies have examined the pneumatization degree of TB, as it has a notable impact on the pathogenesis of otitis media and cholesteatoma[5,6,20,22-24]. From a surgical perspective, the positional relationship between the mastoid segment of the facial canal and surrounding structures is crucial during posterior tympanotomy. Variations related to mastoid pneumatization may alter the surgical corridor and influence the risk of facial nerve injury. Therefore, preoperative evaluation of mastoid pneumatization on CT may help surgeons anticipate anatomical variations and improve surgical safety. It has been reported that there is still limited information regarding the development of mastoid pneumatization, particularly in the pediatric population[25]. This study presents data on how mastoid pneumatization varies across age groups in children and how the pneumatization degree affects the relationship of the facial canal mastoid segment to the surrounding anatomical structures.

Diamant[26] was the first to describe scientific and systematic studies on TB and its mastoid air-cell system. Diamant[26] demonstrated that the mean mastoid area in a healthy adolescent measures approximately 12.07 cm^2, and that mastoid pneumatization reaches completion around 15 years of age in boys and 10 years in girls. Lee et al.[27] noted that mastoid pneumatization volume expands markedly from birth through the early years of the second decade. In addition, Virapongse et al.[1] described a positive correlation between TB pneumatization and age. Although various methods have been used to evaluate TB pneumatization in the literature, radiological assessment is considered the primary approach[20]. In the present study, TB pneumatization in children aged 0–18 years was evaluated using CT images and classified into four groups, hypo-, moderate-, good-, and hyper-pneumatization according to the system proposed by Han et al.[20] When pneumatization degrees were compared across different age periods, a significant difference was observed among the groups. While most newborns exhibited hypopneumatization, pneumatization progressively increased until the postpubertal period. Wang et al.[28] reported that pneumatization does not differ between sexes or sides. Zhao et al.[29] who measured 3D pneumatization volume in children, found a high concordance between sides, with statistically significant right–left differences only in girls aged 9 and 11 years. In current study, although no sex-related differences were identified, pneumatization differed significantly between sides.

TB pneumatization has been reported to influence both the dimensions and the course of the facial canal[8,30-33]. İnal et al.[32] demonstrated that facial canal dimensions were smaller in well-pneumatized mastoids on CT. Another study showed that the degree of mastoid pneumatization significantly affects the distance between the tympanic segment of the facial canal and important surgical landmarks such as the scutum[33]. Regarding its relationship with the sigmoid sinus, Aslan et al.[30] reported in a cadaveric study that increased pneumatization around the sinodural angle was associated with a greater distance between the sigmoid sinus and the vertical (mastoid) segment of the facial nerve. An HRCT-based study comparing well- and poorly-pneumatized TB also found that the distance between the facial canal and the EAC was greater in poorly pneumatized bones[34]. Wang et al[28] further indicated that better pneumatization is associated with a more anterior position of the mastoid segment of the facial nerve and a narrowing of certain surgical corridors. Dai et al.[6] reported a significant positive correlation between mastoid pneumatization volume and the distance from the facial nerve to the lateral border of the mastoid process. In our study, dividing pneumatization into four categories allowed a more detailed assessment, and we found that hyperpneumatized temporal bones exhibited significantly greater distances between the facial canal and both the sigmoid sinus and the mastoid surface (Table 4). Although increased distances in hyperpneumatized bones may enlarge the surgical window during posterior tympanotomy, the variability in the three-dimensional course of the facial nerve may simultaneously complicate accurate risk assessment for iatrogenic injury.

This study has several limitations. First, although the sample size was substantial, the retrospective single-center design may limit the generalizability of the findings. Second, because the study population consisted solely of pediatric patients without middle ear disease, the results may not fully reflect anatomical characteristics in pathological conditions. Future multicenter studies with larger and more diverse cohorts, including patients with otologic disorders, are needed to validate and expand upon these findings.

This study demonstrates that mastoid pneumatization in the pediatric population follows a distinct age-related developmental pattern and that the degree of pneumatization significantly influences the anatomical relationships of the mastoid segment of the facial canal. The reference data obtained indicate that the level of pneumatization can directly affect the surgical window and the positional safety margins of the facial nerve, particularly during posterior tympanotomy. Preoperative assessment of mastoid pneumatization using CT may help predict variations in the surgical corridor and contribute to safer pediatric otologic surgery. Future studies with larger, multicenter cohorts and longitudinal designs are needed to further validate these findings and to explore the impact of pneumatization patterns on surgical outcomes. Additionally, integrating radiological and intraoperative data may provide more comprehensive insights into the dynamic anatomical changes influencing surgical safety.

Author Contributions: Concept/Design : SSA, SG; Data acquisition: SSA, AEK; Data analysis and interpretation: SSA; Drafting manuscript: SSA; Critical revision of manuscript: SG, PK; Final approval and accountability: SSA, SG, AEK, PK; Technical or material support: SG; Supervision: SG, PK; Securing funding (if available): n/a.
Ethical Approval: Ethical approval was obtained from Gaziantep University Non-Interventional Clinical Research Ethics Committee (Approval no: 2024/243; dated 31.07.2024).
Peer-review: Externally peer-reviewed.
Conflict of Interest: Authors declared no conflict of interest.
Financial Disclosure: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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