PNEUMATIZATION PATTERNS IN THE TEMPORAL COMPONENT OF THE TEMPOROMANDIBULAR JOINT – A CONE-BEAM COMPUTED TOMOGRAPHY ORIGINAL STUDY AND REVIEW

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ABSTRACT
Aim of the study This study aimed to establish the pneumatic patterns of the temporo-mandibular joint (TMJ) in cone-beam computed tomography (CBCT) and to review the specific literature as compared to the results. **Material and methods** A retrospective study of the archived CBCT files of 111 patients was performed (i.e.222 temporal bones). The TMJ temporal bone area was analyzed on planar cuts (axial; coronal and sagittal), and grading systems were established for each plane to indicate the degree of the pneumatic air tract extent. **Results** Twenty-nine different patterns of pneumatization were found. Fifty-five percent of the lot had no pneumatization at all in the TMJ area, while 20.3% presented air cells only in the posterior root of the zygomatic arch. Prevalence in the remaining patterns was less than 2% for each pattern. **Conclusions** Air cells in the temporal bone are unpredictable and impossible to locate without the help of high accuracy radiological investigations. Their presence may impact the function of the TMJ and are to be considered as risk factors for intraoperative and postoperative complications.

Key words: temporal bone; cone-beam computed tomography; air cells; zygoma

INTRODUCTION

Pneumatic air cells are defined as being air-filled cavities, of different sizes, with epithelial lining formed within bony confinement[1]. The temporal bone results from the fusion of different separate parts, such as the squama and the petrous part[2]. The pneumatization process of the temporal bone begins in the fetal period and continues after birth, till around the age of five, when it is considered to have reached its adult structure; afterward, only limited development of narrow new air cells are present[3].

Pneumatization of the temporal bone occurs in five primary regions: middle ear, perilabyrinthine, petrous apex, squamomastoid and accessory[4]. Thus, the pneumatization usually involves the mastoid process, the perilabyrinthine region and the petrous apex but in rare cases, pneumatization occurs within the zygomatic process (ZP), the articular eminence (AE or articular tubercle - AT), the temporal squama, the occipital bone or around the temporomandibular joint (TMJ) area[5]. Nonetheless, styloid and facial cells were described in rare occasions[1, 4] and dehiscent cells towards the extradural space and the TMJ' upper space were also documented[6]. It seems that pneumatization is highly variable in the tympanic plate as well[7]. One could observe that the mandibular fossa (MF) is not listed as a potential anatomic situs for such pneumatization.

Pneumatization refers to both the progression of the mucosa into the bone and the presence of epithelial-lined air cells that remain after the pneumatization process [5].

Interestingly, there was no soft tissue lining the tortuous cavity of a PAT during an eminectomy procedure, as documented macroscopically[8].

The epithelial-lined air cell networks are ubiquitous in hominid temporal bones [5]. The computed tomography could evaluate and differentiate down to 2-millimeter large pneumatic cells from bone marrow[1]. The CBCT offers the same accuracy on bone structures as the CT but with a lower radiation dose needed and at a lower price[9].

The current study was aimed at using CBCT for documenting the three-dimensional patterns of pneumatization of the temporal components of the TMJ and to compare the gathered evidence with data in the existing literature.

MATERIAL AND METHODS

A retrospective study was performed on archived CBCT files. Random patient files were selected. Patients with any fluid or mass present in any of the temporal bone air spaces, with fractures of the temporal bone or with bone destruction were excluded from the sample. A total of 111 files (222 TMJs; 42 males and 69 females) remained to be used for evaluation of air cell presence within the AT and MF. The patients had given written informed consent for all medical data (including CBCT scans) to be used for research purposes, provided the presented results are anonymized.

All patients have been scanned with an iCat CBCT machine (Imaging Sciences International, resolution 0.250, FOW 130, image matrix size 640x640). Collected data were evaluated both with the iCatVision software and the Planmeca Romexis Viewer 3.5.0.R software, as previously detailed [10, 11]. Relevant anatomical features were exported as image files.

Grading systems

The transversal 6-point grading system of the PAT

On planar axial slices, the transversal pneumatization of the AT was classified according to its medial (centripetal) extent in five "T" types: T0 – no pneumatization; T1 – the pneumatization is external as referred to the lateral pole of the mandibular fossa (pneumatized anterior zygomatic root); T2 – the pneumatization advances medially up to the outer third of the AT; T3 – the pneumatization advances medially up to the middle third of the AT; T4 – the pneumatization advances medially up to the inner third of the AT; T5 – the pneumatization of the AT extends medially as referred to the medial pole of the mandibular fossa. Isolated, but not continuous centripetal localizations of air cells in the AT were indicated by the suffix "U" added to the respective landmark.

The transversal 4-point grading system of the MF pneumatization

On planar coronal slices, the transversal pneumatization of the MF was classified in four "C" types: C0 – no pneumatization; C1 – pneumatization up to the outer third of the MF (pneumatized posterior zygomatic root); C2 – pneumatization up to the middle third of the MF; C3 – pneumatization up to the inner third of the MF.

The sagittal 4-point grading system of the AT and MF pneumatization

On sagittal slices the posterior-to-anterior pneumatization of the temporal component of the TMJ roof was classified in four "S" types: S0 – no pneumatization; S1 – pneumatization advances superior to the mandibular condyle to the thin segment of the MF; S2 – pneumatization of the MF and the posterior half of the AT; S3 – the pneumatization reaches the anterior half of the AT. Isolated, but not continuous localizations of air cells in the temporal squama were indicated by the suffix "U" added to the respective landmark.

An example of the applied grading system for a right TMJ is shown in **Figure 1**.

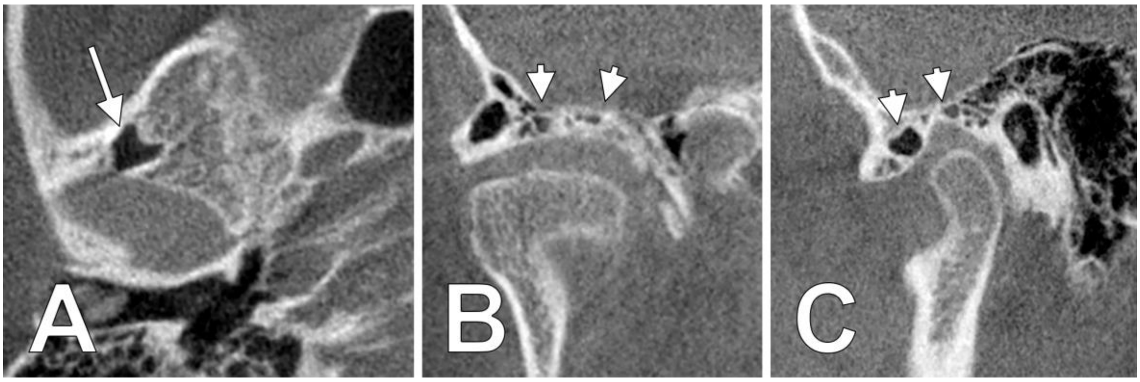

Figure 1 Example of the grading system - pattern T2U-C3-S2. Planar slices of the temporal component of the temporal joint, axial (A), coronal (B) and sagittal (C). A large air cell is found in the middle third of the articular tubercle (type **T2U**, A-arrow). The mandibular fossa pneumatization advances in its inner third (type **C3**, B-arrowheads). Air cells occupy the mandibular fossa and the posterior half of the articular tubercle in the sagittal section (type **S2**, C-arrowheads). The prevalence of this pattern was 0.9%.

RESULTS AND DISCUSSIONS

The transversal pneumatization of the articular tubercle ("T" types)

The "T" types were documented on axial cuts (**Figure 2**) and it resulted that the T0 type (no transversal pneumatization of the AT) was the most frequent (81%), being followed by the T2 type (11%). The T1 type (the pneumatized anterior root of the ZP) was found in only 2% of the TMJs. Rare types, such as T3, T4 and (T2+T3)U were present only in 1% of TMJs (**Figure 3**).

The coronal pneumatization of the mandibular fossa ("C" types)

On coronal slices (**Figure 4**), C0 had the highest prevalence (56% of TMJs) implying that only 44% of the MFs contained air cells (**Figure 5**).

The sagittal (posteroanterior) pneumatization of the glenoid fossa ("S" types)

In 82% of TMJs, no sagittal pneumatization of the temporal component was found (**Figure 6**). The chart of sagittal pneumatization is presented in **Figure 7**.

Three-dimensional models of TMJ temporal pneumatization

A total of twenty-nine different models were counted. In 122 of 222 TMJs (55%) the combination T0-C0-S0 was found, thus the pneumatization extension in the periarticular region occurred in less than half of the temporal bones. From all the found combinations, the most frequently found was the T0-C1-S0 pattern (45/122 TMJs - 20.3%), suggesting that air cells are more likely to extend to the posterior root of the zygomatic arch. The remaining anatomical patterns had a prevalence of under 2% as shown in **Table 1**.

The process of pneumatization begins during the last few weeks of the fetal period but it mainly occurs during postnatal growth [5, 12]. The epithelium expands surrounded by an osteoclastic front, thus leaving an interconnected air cells network throughout the temporal bone [5]. Although the main

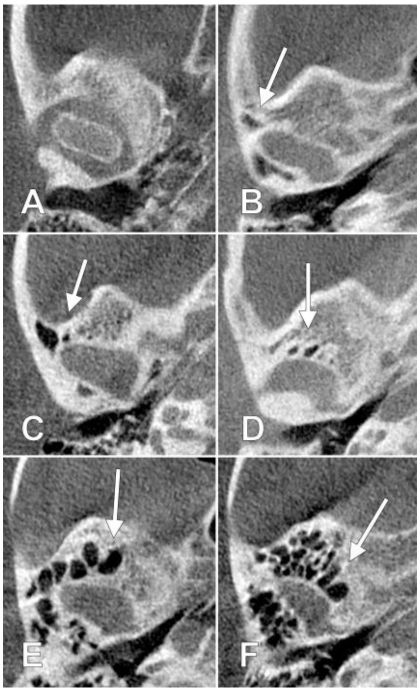

Figure 2 Planar axial slices of the articular tubercle demonstrating the "T" types. A: T0 – no pneumatization; B: T1 – pneumatized anterior zygomatic root (arrow); C: T2 – pneumatization (arrow) advances to the outer third of the articular tubercle; D: T3 – pneumatization (arrow) extended to the middle third of the articular tubercle; E: T4 – pneumatization (arrow) in the inner third of the articular tubercle; F: T5 – pneumatization (arrow) medially to the inner pole of the mandibular condyle

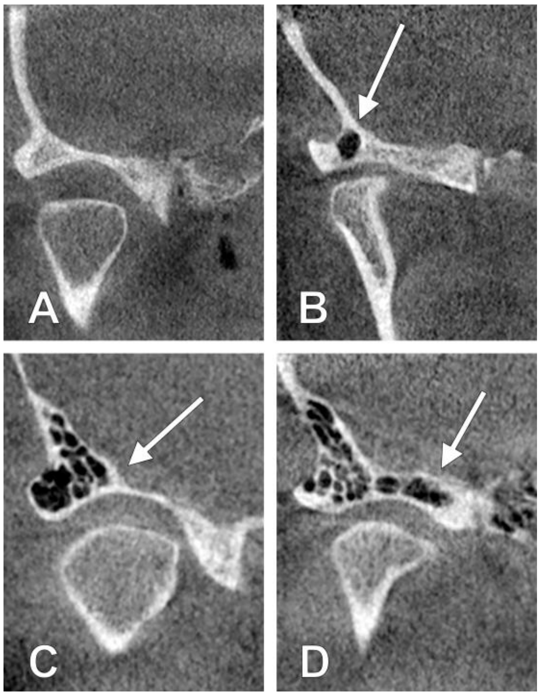

Figure 4 Planar coronal slices of the mandibular fossa (MF) demonstrating the "C" types. A: C0 – no pneumatization MF; B: C1 – pneumatized posterior zygomatic root (arrow); C: C2 – pneumatization extended in the medial third of the MF (arrow); D: C3 – complete lateromedial pneumatization of the MF (arrow)

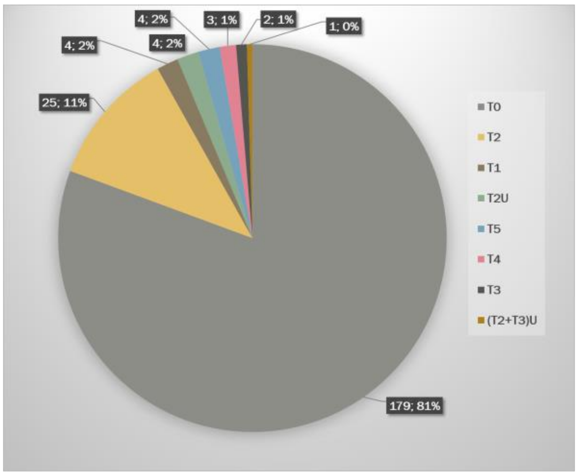

Figure 3 Chart of the number and prevalence of "T" types (N = 222 temporomandibular joints)

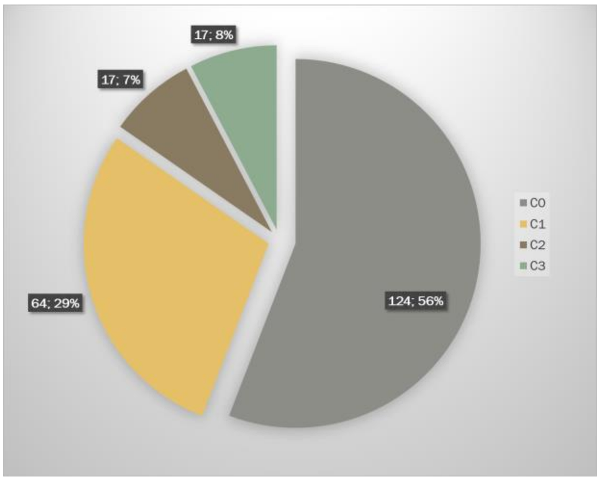

Figure 5 Chart of the number and prevalence of "C" types (N = 222 temporomandibular joints)

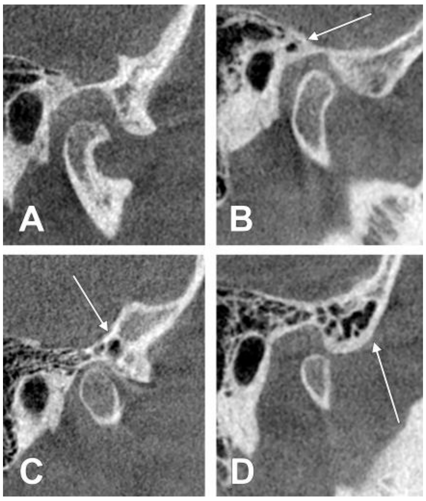

Figure 6 Planar sagittal slices of the temporomandibular joint demonstrating the "S" types. A: S0 – no pneumatization; B: S1 – pneumatization of the posterior articular tubercle (arrow); C: S2 – pneumatization extended in the posterior half of the articular tubercle (arrow); D: S3 – pneumatization reaching the anterior half of the articular tubercle (arrow)

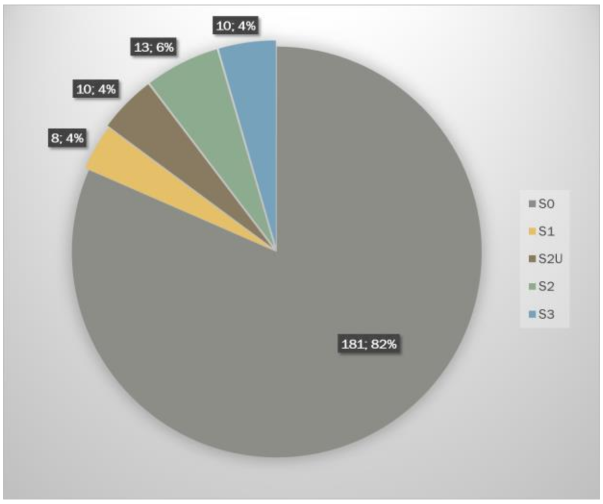

Figure 7 Chart of the number and prevalence of "S" types (N = 222 temporomandibular joints)

Table 1 Prevalence of the combined grading patterns in 111 cases documented bilaterally

Combination pattern	No./222 sides	Prevalence (%)
T0-C0-S0	122	55.0
T0-C1-S0	45	20.3
T5-C3-S3	4	1.9
T2-C1-S2U	4	1.8
T2-C2-S2U	4	1.8
T0-C2-S1	2	0.9
T1-C1-S2	2	0.9
T2-C2-S0	2	0.9
T2-C3-S0	2	0.9
T2-C2-S2	2	0.9
T2-C3-S2	2	0.9
T2U-C3-S2	2	0.9
T0-C2-S0	3	1.4

T0-C1-S1	3	1.4
T2-C1-S2	3	1.4
T4-C3-S3	3	1.4
T2-C1-S0	5	2.3
T0-C0-S1	1	0.5
T0-C3-S1	1	0.5
T0-C0-S2U	1	0.5
T1-C1-S0	1	0.5
T1-C3-S3	1	0.5
T2-C2-S1	1	0.5
T2-C1-S3	1	0.5
(T2+T3)U-C3-S2	1	0.5
T2U-C2-S0	1	0.5
T2U-C2-S2U	1	0.5
T3-C2-S2	1	0.5
T3-C3-S3	1	0.5

tracts are formed by the fifth year of life, the pneumatization continues throughout puberty, forming accessory air cells [13] and enlarging itself[14], and ceases during the adult stage[15].

Two different theories consider the importance and design of the pneumatization pattern. The hereditary theory states that pneumatization is a genetically-driven process and that the symmetry of the system advocates in its favor, justifying the asymmetry as just a consequence of individual variability[16]. This would suggest that the extent of the pneumatic air system is a predisposing factor for otologic disturbances, such as tympanosclerosis, atelectasis, cholesteatoma, etc., and it affects the rate of success during middle ear surgery[17]. The environmental theory explains asymmetry as a result of perturbation, due to a form of chronic inflammation which has inhibited the pneumatization process on the affected side[18]. Beaumont demonstrated that the pneumatization process does not occur in the absence of air or [19].

Pneumatization of the temporal components of the TMJ was regarded as "*zygomatic air cell defect (ZACD)*" [14, 20-27], before being reconsidered as „*zygomatic air cells*" (ZAC) [14]. Frequently enough, the PAT was viewed as a „*radiolucency in the zygomatic process of the temporal bone*" [28] or as an "*asymptomatic radiolucent appearance defect similar to that seen in the mastoid process that occurs in the zygomatic process of temporal bone*" [29]. Air cells within the ZP of the temporal bone were considered as PAT [14, 30] although the ZP and the AT are anatomically different structures. This could explain the inconsistencies in the PAT prevalence results from previous studies.

Furthermore, as it results from **Table 2,** numerous studies of the PAT used panoramic radiography (PR) implying that the analysis was on an overlap of structures[31], and differential diagnosis between PAT and another radiolucency (aneurysmal bone cyst, hemangioma, giant cell tumor, eosinophilic granuloma, fibrous dysplasia, metastatic tumor deposits) had to take place[14].

Table 2 Prevalence of pneumatized temporal joint surfaces in different studies. Numerous studies did not differentiate the pneumatization of the glenoid fossa from that of the articular tubercle of TMJ. PAT: pneumatized articular tubercle; AE: articular eminence; PRGF: pneumatization of the roof of the glenoid fossa; MF: mandibular fossa; PZR: pneumatization of the zygomatic root; PR: panoramic radiography

Method of study	Patients number/TMJs	Prevalence of pneumatized AE (PAT)	Prevalence of pneumatized MF (PRGF)	Prevalence of PZR	References
CBCT	111/222	19 (T types)	44 (C types)	29 (C1 types)	present study
CBCT	100/200	10	33.5	44.5	[32]
CBCT	111/222	65.8	11.7	–	[33]
CBCT	514/1028	8	–	–	[34]
CBCT	100/200	12	52	5	[35]
CBCT	658/1316	21.3	38.3	–	[30]
CBCT	225/450	9.55	–	–	[36]
PR	1061/2122	2.6	–	–	[37]
PR	784/1568	1.0	–	–	[31]
CT	100/200	12	51	5	[38]
CBCT	250/500	12.2	64	–	[39]
PR	1006/2012	1.88	–	–	[15]
PR	1049/2098	1.62	–	–	[13]
CBCT	825/1650	2.54	–	–	[28]
PR	8107/16214	1.03	–	–	[29]
PR	600/1200	2.5	–	–	[26]
PR	2500/5000	2.5	–	–	[22]
PR	7755/15510	1.82	–	–	[25]
PR	2600/5200	3.6	–	–	[23]
PR	1400/2800	2.2	–	–	[40]
PR	1084/2168	1.85	–	–	[41]
PR	2734/5468	1.5	–	–	[14]

Some authors even tried to analyze the locularity of air cells on PR[42]. A more accurate exploration of this area can be obtained by the use of CT/CBCT and magnetic resonance imaging (MRI). A study comparing the two methods, PR and CBCT, concluded that the panoramic radiograph was a poor choice for detecting the presence of air cells when compared to CBCT [43]. Also, care should be taken during MRI evaluation of the TMJ because an area of low signal overlying the glenoid fossa could either indicate a temporal bone pneumatization or a lesion of fibrous or osseous nature[44].

Table 2 also depicts that the CBCT has been used to evaluate the peri-TMJ pneumatic system of the temporal bone. Demirel et al.[39] studied the sagittal extension of the mastoid process in 250 patients, including pneumatization of the TMJ's temporal components (glenoid fossa and AT). Wong and Munk[44] used a sagittal four-point grading system (0/1/2/3) of ZAC spreading through an arbitrary center of the glenoid fossa, thus not evaluating the transversal spreading of such pneumatizations. Nades et al. [32] noted the air cell's appearance in the sagittal as well as the coronal plane, offering a more three-dimensional representation of the pneumatic extent in the anterior region of the temporal bone. Nonetheless, given that they analyzed the air cell presence in only one section (the parasagittal and paracoronal planes were set according to the central portion of the glenoid fossa, in its greatest mid-lateral extension, from the axial reconstructed image), the information seemed to be incomplete, especially when doing a unilocular/multilocular statistical investigation. The current study was designed to overcome the flaws noticed in previous articles, by supplying data in all three planes and applying a more comprehensive grading scale. **Figures 8** and **9** depict the importance of a three-dimensional examination, demonstrating that what seems to be a unilocular cell (a unique pneumatic cell isolated from the rest of the air tract) in one or two planes, might be infirmed in the third one.

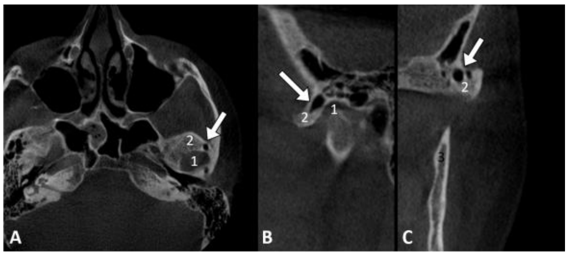

Figure 8 Analysis of a pneumatic cell (White arrow) in all three planes axial (A), sagittal (B) and coronal (C) to determine it's unilocular state. Although it is a strained cell and seems as a unilocular pneumatization in the axial section, it can be noticed in the other planes it is not a unique cell

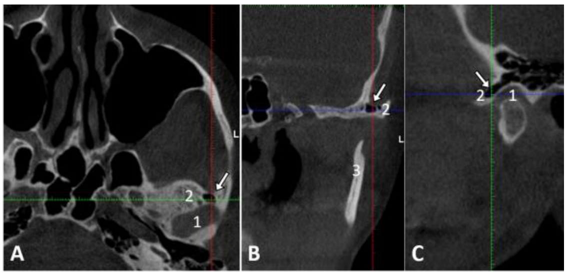

Figure 9 Analysis of a pneumatic cell (White arrow) in all three planes axial (A), sagittal (B) and coronal (C) to determine it's locularity state. Although both in the axial and coronal plane it seems to be an isolated cell (not a unique one), this fact is infirmed in the sagittal plane. Primary axis lines were kept to identify the sections crossing through the air cell.

Temporal air cells help in lightening the weight of the skull [18] and act as an "air reservoir" during eustachian tube dysfunction[45]. Otitis media has been frequently linked with an insufficiently developed pneumatic system[5] and TMJ ankyloses can result as a complication from otitis media or oto-mastoiditis[35] thus, the effect of pneumatization absence on the TMJ.

On the other hand, air cell tracts favor the spread of various pathologies, such as inflammation, tumors of the mastoid process and ear[33]. By pneumatic expansion in the root of the zygoma, the glenoid tubercle and the mandibular fossa, air cells can be found surrounding the TMJ, sometimes "separated by bone of only a small fraction of a millimeter thick"[2]. In some cases, they offer direct communication with the inner articular space, through dehiscent cells[6] or by bone erosion and perforation[2]. Singleton[2] mentioned that infection in the suprazygomatic air cells associate pain and tenderness in that area, and, if such cells are overlying the TMJ, there will be pain and tenderness in the joint that would be accentuated by chewing and opening of the mouth. It has also been suggested that they are a predisposing factor for fractures due to the lesser bone density[35, 46]. Complications and problems, such as development and spread of postoperative infection, insufficient screw stability, impediment in obtaining a smooth posterior slope surface, during TMJ surgical procedures (eminectomy, eminoplasty or prostheses placement) can be attributed to periarticular pneumatization [8, 33-35, 46]. The temporomandibular disorder was investigated in correlation with the presence of ZAC, resulting that diagnosed positive patients showed more pneumatization in the TMJ area[46].

Still, both the presence or absence of a mastoid pneumatic system were considered variants of the normal, before Wittmaack published his findings and the environmental theory[3], and, to this day, the link between the degree of pneumatization and otological dysfunction remained unclear. Whether Wittmaack was right, and the pneumatic system of the temporal bone follows a more regular mode of development than has been thought, is still up to debate. Given that the prevalence of pneumatization in the TMJ area was of 45%, we could agree with Wittmaack, that pneumatization is a natural phenomenon subjected to local individual factors (congenital defects, bone structure, nearby inflammatory processes, trauma, etc) and thus, resulting in variation between individuals. But, we have to raise some questions regarding the existence of an ontogenetic pattern, taking into account the many variants obtained (**Table 1**). Although, the temporal bone pneumatization has been used to assign a phylogenetic status to fossils, and primates, such as chimpanzees and gorillas, show consistently present ZACs and squamous air cells[5], the evolutionary and developmental changes in humans seem to have disregarded the former rules.

CONCLUSIONS

The anatomy of the pneumatized AT and MF is individually variable. Air cells in the temporal bone are ubiquitous and impossible to locate without the help of high accuracy radiological investigations. Their presence may impact the function of the TMJ and are to be considered as risk factors for intraoperative and postoperative complications.

CBCT can offer a better understanding of the bone morphology, for it can precisely assess these structures in a three-dimensional view.

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