Review Article

Prevalence and pattern of pneumatization of tempromandibular joint using CBCT: A systematic review and meta-analysis

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ABSTRACT

This study aimed to systematically review and meta-analyze the prevalence of pneumatization of temporal components of temporomandibular joint (TMJ) as well as its prevalence regarding gender, laterality, and locularity using cone beam computed tomography (CBCT) images in different populations. This secondary study was performed using a systematic search of literature until 2020 on Pubmed, Web of Science, Scopus, ProQuest, and Embase databases. The extracted data was entered in Stata 12 software and to integrate the results, the meta-analysis method was used and the effect size of prevalence was calculated. In the present study, the prevalence of PAT was estimated at 24% based on the subjects; PAT was calculated at 19% in men and slightly lower in women (18%). Unilateral prevalence was higher than bilateral PAT (60% vs. 40%). Also, the multilocular pattern was reported more commonly than unilocular PAT (70% vs. 30%). The prevalence of PGF was estimated at 31% based on the subjects, which is higher than the prevalence of PAT. Regarding the significant prevalence of PAT and PGF detected in CBCT imaging of the studied populations, PAT and PGF are considered important normal anatomical variations that should be mentioned in radiologic reports.

Keywords: Cone beam computed tomography, Pneumatization, Articular tubercle, Glenoid fossa, Systematic review, Meta-analysis

Introduction

In the field of oral and maxillofacial radiology, having adequate knowledge regarding anatomic phenomena, their prevalence, and the most common patterns is the first step for the radiologist to properly interpretation of the radiographic images and make differential diagnoses [1]. This rule is also applied to the radiographic evaluation of bony structures in the maxillofacial region and is essential for differential diagnoses of abnormal conditions of this tissue including pneumatization.

Pneumatization is defined as the presence or development of air-filled cavities in bone [2]. These cavities can be seen in different bones; although most of them are found in skull bones [3]. Paranasal sinuses and mastoid processes are examples of pneumatization in the skull bones. Moreover, accessory air-filled cavities can be detected in the zygomatic process of the temporal bone, including the roof of the Glenoid Fossa (GF) and Articular Tubercle (AT) [2]. Generally, the extension of pneumatization in the temporal bone has a large diversity [4]. Allam classified these air-filled cavities based on their location: middle ear, Mastoid, apex part of petrous, around the labyrinth, and lateral areas. Lateral areas also include four groups: Zygomatic, Styloid, Occipital, and Squamous [5].

For the first time in 1985, Tyndal and Matteson described air cells around TMJ similar to those found in the mastoid process and ethmoid bone. The general characteristics of these air cells around the TMJ are asymptomatic radiolucent cavities in the zygomatic process with the extension to the AT but not beyond the zygomaticotemporal suture and have no enlargement and bone destruction [2]. In terms of laterality, pneumatization may be unilateral or bilateral, and concerning internal structure, it can be a well-defined solitary radiolucency (unilocular), or a radiolucent area divided into smaller spaces by thin septa (multilocular) [1, 6].

The functional benefits of pneumatization of the temporal bone would be minimizing the weight of the skull, increasing the resonance, receiving and scattering the sound, and acting as the air resource for the middle ear [7, 8]. In addition, pneumatization of the temporal bone assists in the absorption and distribution of the stroke in lateral traumas which results in the protection of vital structures inside the temporal bone [9]. There is no consensus on the timing of the onset and end of this phenomenon [5]. It is claimed that pneumatization of the temporal bone starts in the embryonic stage and is almost completed in 9-10 years of age [3]. Some researchers also suggest that this process is continued until the age of 10 in women and 15 in men [10].

Although Pneumatization of the Articular Tubercle (PAT) and Pneumatization of the Glenoid Fossa (PGF) are considered a normal variation, their diagnosis is critical since it is representative of regions of weak bone resistance that facilitates the spread of numerous pathologies including inflammation, tumor, and fractures to the TMJ complex [10]. Hence, this promoted extension of inflammation may lead to the extension of otitis media and mastoiditis to the TMJ (septic arthritis of TMJ) that can result in TMJ ankylosis in younger ages; this can negatively affect the development and growth of the mandible which leads to problems including malocclusion, facial asymmetry, and mandibular retrusion [2 ,10]. Recently, in patients with severely atrophic maxilla, Zygomatic bone has been used for implant placement. Utagawa and colleagues have reported that occlusal stresses in such cases are transferred through frontal and temporal processes of the zygomatic bone; therefore, the presence of air cells in zygoma leads to bone fracture due to reduced bone volume and resistance [7].

Characteristics of the temporal bone are important for planning the surgical technique in this region. Mostly, the temporal part of the TMJ usually has variable morphology and pattern of pneumatization [9]. According to this, PAT and PGF may increase the risk of complications arising from TMJ surgical procedures (including eminectomy and miniplate insertion); since accidental penetration to the pneumatized areas may cause rupture of the dura and subsequent CSF leakage and intracranial bleeding or infection [7, 10, 11]. Chicarelli *et al*. recommended an absolute contraindication for Eminectomy in patients with high levels of pneumatization [11]. Accordingly, Skull fractures may extend through these defects (PAT and PGF), hence air spreading to the glenoid fossa. As a result, detecting such defects for selecting precautionary interventions before surgery and the ideal surgical method in order to minimize the risk of most of the detrimental complications is of significant importance [10].

Various imaging modalities have been used for the evaluation of PAT and PGF. Panoramic radiography previously was the modality of choice for radiographic evaluation (due to being widely available as well as lower cost and radiation dosage in comparison to CBCT) [10]; although, anatomical complexity of the region and superimposition of the adjacent structures (especially skull base) leads to a less accurate evaluation of the area and dimensions of the aeration [7, 8]. The prevalence of PAT is reported to be 1-6.2 % by using panoramic radiography [10].

Computer tomography (CT) is the modality of choice for the evaluation of the bony structures and air spaces in the skull base [9]. Nowadays, Cone-beam Computed Tomography (CBCT) has been developed as a substitute imaging modality for conventional CT for diagnostic purposes in the oral and maxillofacial region. It has been shown that CBCT produces superior results concerning the imaging of TMJ [4]. This modality provides volumetric images with higher spatial resolution compared to CT due to thinner slices and smaller isotropic voxels; also, the cost of scanning and its radiation dose level is lower compared to the MDCT [9, 10]. The resolution of CT allows the differentiation of air cavities with a size of 2 mm from the bone marrow; while the submillimeter resolution is available in CBCT imaging [8].

Finally, CBCT is reported to be beneficial for studying PAT and PGF owing to the ability to provide accurate and detailed scans in three dimensions (coronal, sagittal, and axial planes) and simultaneous presentation of cross-sectional cuts. CBCT, as an advanced diagnostic tool for maxillofacial imaging, provides the possibility for accurate diagnosis and better display of areas affected by pneumatization [3, 7). Moreover, according to Patel, the most clinically beneficial aspect of CBCT is the complicated software that allows the massive collected data to be analyzed, processed, or reconstructed with a similar format produced in other imaging modalities [12).

In the most recent articles, CBCT is used for the assessment of pneumatization of the temporal components of TMJ. The outcomes of these studies have reported a higher prevalence of pneumatization and better evaluation of its features for CBCT in comparison to 2-D imaging modalities.

Regarding numerous evidence in this field and controversial outcomes as well as the importance of the evaluation of the temporal bone in CBCT imaging which has been noticed in recent years, it seemed that performing a comprehensive study on available results could lead to increased knowledge and accuracy about this issue for radiologists and oral surgeons. Some studies have qualitatively reviewed the available research in this field as well as reported their outcome [1, 3, 10, 12, 13]; still, there was no systematic review and meta-analysis available evaluating this topic. Therefore, the present systematic review study aimed to evaluate the prevalence of pneumatization of the temporal components of TMJ in addition to reporting the prevalence regarding gender, laterality, and locularity using CBCT in different populations. The results of this study were quantitatively summarized using meta-analysis as well as qualitative evaluation.

Materials and Methods

Protocol Registration

This systematic review was conducted in accordance with the Preferred Reporting Items for the Checklist of Systematic Review and Meta-Analysis (PRISMA) [14].

The protocol of this study was registered on the International Prospective Registry of Systematic Reviews (PROSPERO) and approved with the code CRD42020212842.

Sources of Information and Search

Search Strategy

This research was implemented as a secondary study in the form of a systematic review and meta-analysis. A comprehensive and systematic search of articles was done till the end of 2020 on Pubmed, Web of Science, Scopus, ProQuest, and EMbase databases in order to access all articles published in the English language related to this topic. Searching was done using keywords confirmed in Medical Subject Headings (MeSH) and studying published articles in this field by using "AND" and "OR" operators. Nomenclatures, searched words, and combinations are attached in Appendix 1. Search strategies in each database are also attached in Appendix 2. For having access to all related data, no limitations were set regarding time and geographical scope. Since studies evaluating "prevalence" can be considered a subset of other studies, the keyword "prevalence" was not included to prevent false fall of articles and therefore, the maximum number of articles would be accessible.

After completing the search and importing the data to the reference manager software (Endnote X7, Thompson, Reuters, New York, NY), duplicated articles were eliminated. The final updated search was done on January 23, 2021.

Study Selection

The title, abstract, and then the full text of the articles were evaluated regarding inclusion and exclusion criteria. This process was done separately by two researchers. Any disagreement was discussed until a consensus was reached.

Inclusion Criteria

All cross-sectional studies that evaluated the prevalence and pattern of pneumatization of temporal components of TMJ by using CBCT on only human samples were included in the present study.

Exclusion Criteria

Case reports and review studies, letters to editors, personal statements, book chapters, conference abstracts, guidelines, pilot studies, and studies in which evaluation of prevalence and pattern of pneumatization was done using panoramic imaging were excluded from this study.

Scientific Validity Assessment of Articles and Sources (Scoring Method)

Evaluation of the quality of selected articles was done using the proposed checklist of American National Institutes of Health (NIH) available on (https://www.nhlbi.nih.gov/health-topics/study-quality-assessment-tools). Based on this checklist, the aim of the study, target population, sampling methods, variables, data collection and measuring, statistical analysis, and the outcomes of the studies were criticized by two researchers separately. For observational studies, there are 14 Yes/No questions. This checklist is common between cohort and cross-sectional studies; and since all selected articles in this study were cross-sectional, only 9 questions out of 14 were applicable in this study (Appendix 3). Hence, the Score range would be between 0 to 9. Scores higher than 6 were considered "good quality"; scores between 3-6 were considered "medium quality"; and scores less than 3 were regarded as "low quality". In this study, only articles with medium to good quality were included.

Data Extraction

Among all studies receiving the necessary critique score, the following data were extracted: 1-study characteristics (Author name, publication year, location where the study was implemented, type of study); 2-Sample features (sample size (number of participants, and TMJs), gender and age distribution, age mean and standard deviation); 3-Results (the number of PATs regarding the studied participants and TMJs, the number of PATs based on gender, the number of PATs based on laterality, the number of PATs based on locularity, the number of PGFs regarding the studied participants and TMJs, the number of PGFs based on gender, the number of PGFs based on laterality, the number of PGFs based on locularity).

This data was imported into the evidence table.

Statistical Analysis

Data extracted from the included articles were collected in the Excel software in the form of an evidence table and was imported to the Stata 12 software (Stata Corp, College Station, TX, USA). This data was subjected to analysis using the Stata codes named "metaprop" and "metan".

Since different study results have different values, the inverse variance was used for weighting the articles.

Afterward, the heterogeneity of the studies was assessed using Cochran's Q test, and its quantitative value was shown using I^2 statistic in a way that 25%, 50%, and 75% were regarded as "low"; "medium"; and "high" levels of heterogeneity respectively. Nonetheless, in the present study, values higher than 50% were considered heterogeneous, and a proportional approach was adopted. Then, for estimating the best value of each index, determining the consistency of results of the primary studies, and determination of probable factors responsible for contradictory results, we transformed the values to a common effect size. A fixed effect model was used primarily and in case considerable heterogeneity was detected, a randomized effect model was utilized.

In the meta-analysis, the sensitivity analysis approach was applied for the assessment of the resource of heterogeneity based on the amount of extracted data from articles.

Egger's test and Begg's test were used for the evaluation of publication bias. If publication bias was detected using these tests, the Trim and Fill method was used for re-estimation in order to detect the articles with a higher chance of publication and trim the effect of this bias.

Results and Discussion

Study Selection

Overall, 86 articles were detected by searching databases (19 on Pubmed, 21 on Web of Science, 23 on Scopus, 2 on ProQuest, and 21 on EMbase). After eliminating the duplicate articles, 26 studies were left; and because of a relatively limited number of articles available from the systematic search, Grey literature (Google Scholar and Open Grey) was also used and 5 more articles were added finally 31 studies were screened in the selecting phase. Moreover, for completing the search process, all references of these 31 articles were evaluated manually but no extra article was added. In the final updated search, no new article was detected.

Based on the above-mentioned approach for study selection, 2 studies were eliminated regarding the title, 6 were excluded concerning the abstract, and 3 were removed by assessing the full text. As mentioned before, since "Prevalence" can be calculated in each article and be part of the results, the full texts of all 29 articles were carefully studied to ensure their selection. Finally, 20 articles were selected for scientific validity assessment. All 20 articles reached the necessary critique score of the aforementioned checklist and were assessed for data extraction. One study was eliminated at this stage due to the false statistical report [15], and data from 19 remaining articles was collected in the evidence table.

Search results are reported in **Figure 1** (PRISMA flowchart).

General Characteristics of the Studies

Among the 19 articles evaluated in the systematic review, 15 were also subjected to quantitative assessment using meta-analysis. A summary of the characteristics of the selected articles is available in **Table 1**.

The newest articles were published in 2020 [2, 3, 10, 16], and the oldest one was published in 2010 [17]. These cross-sectional studies were implemented in Turkey [2–7, 13, 17, 18], Iran [8, 12, 19], India [1, 16, 20], Brazil [9, 11, 21], and Egypt [10]. The greatest sample size was 1000 persons [3, 7], and the smallest was 62 [20]. The age range was almost similar in all studies; the widest age range was 4-85 [13], and the most limited was 6-24 [17]. The mean age of participants in the study was variable from 18.3 [17] to 51.29 [19], years of age. Regarding similar age groups in these articles, sorting the prevalence of pneumatization based on age groups was not possible; hence, a meta-analysis of prevalence based on age was not performed.

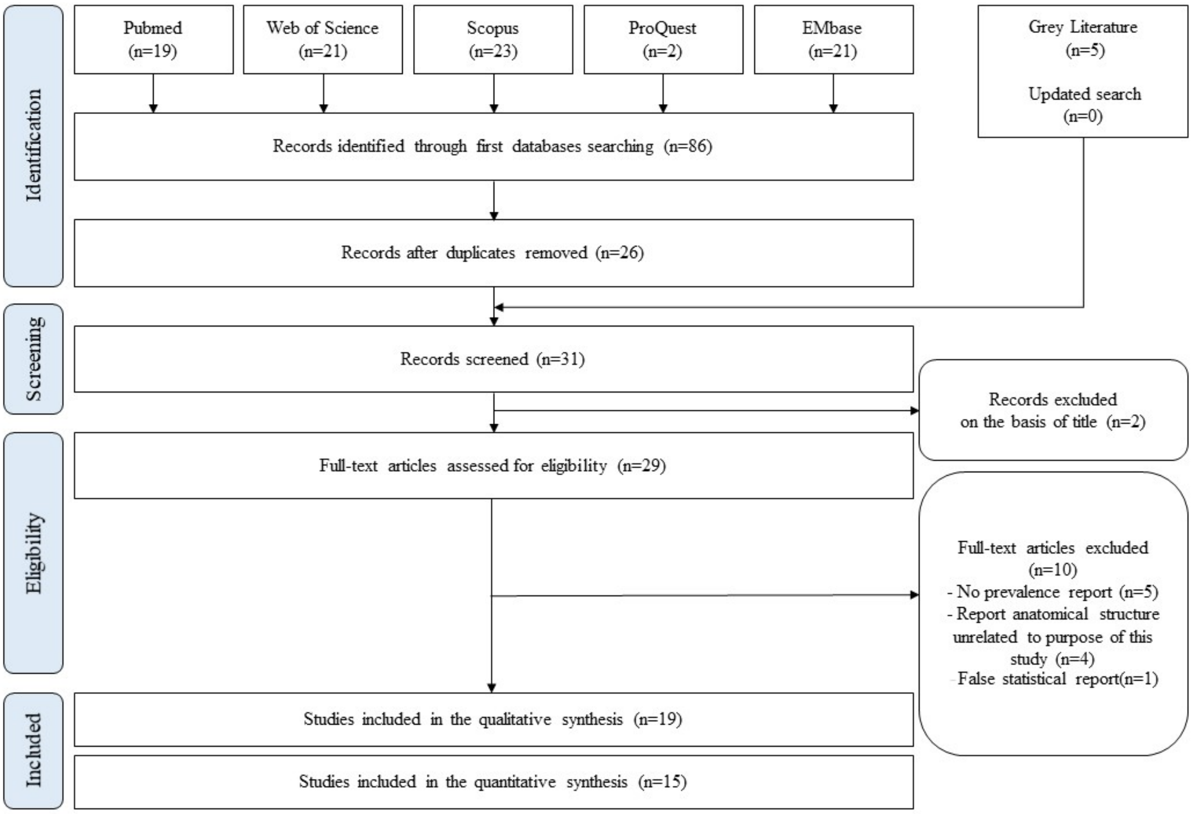

Figure 1. PRISMA flowchart

Table 1. A summary of selected articles.

ID	NIH score	Authors	year	country	Study design	CBCT unit	Technical status: FOV	Technical status: kvp	Technical status: mA	Sample size (N)	Age range (Years)	PAT prevalence (%)	PAT Laterality: uni	PAT Laterality: bi	PAT Locularity: uni	PAT Locularity: multi	PGF prevalence (%)	PGF Laterality: uni	PGF Laterality: bi	PGF Locularity: uni	PGF Locularity: multi	Pneumatization (PAT or/and PGF) prevalence (%)
1	7	Lacin *et al.*[2]	2020	Turkey	cross-sectional	New Tom 5G	12*15	110	1-20	350	18-79	…	…	…	…	…	…	…	…	…	…	84.9
2	7	Salli *et al.*[3]	2020	Turkey	cross-sectional	Planmeca Promax SD Mid	16*16	90	12	1000	16-77	14.7	57.8	42.2	14.3	85.7	47.1	32.3	67.7	4.5	95.5	…
3	8	ElBeshlawy[10]	2020	Egypt	cross-sectional	Planmeca Promax SD Mid	13*16	90	8	210	5-65	19.1	54.3	45.7	…	…	35.24	41.9	58.1	…	…	…
4	5	Shekhawat *et al.*[16]	2020	India	cross-sectional	Carestream CS imaging V.3.5.7	11*17	68-90	4	106	18-80	56	64.4	35.6	…	…	9	70	30	90	10	…
5	6	Buyuk *et al.*[7]	2019	Turkey	cross-sectional	GALILEOS	15*15	98	3-6	1000	18-86	39.1	55	45	26.3	73.7	39.6	50.8	49.2	0.8	90.2	…
6	7	Chicarelli *et al.*[11]	2019	Brazil	cross-sectional	i-CAT Next Generation	17*23	120	38	587	…	16.3	66.7	33.3	11.5	88.5	62.9	34.1	65.9	7	93	…
7	8	Nadaes *et al.*[9]	2019	Brazil	cross-sectional	i-CAT Next Generation	13*16	120	37.07	100	20-60	…	…	…	…	…	…	…	…	…	…	88
8	7	Khojastepour *et al.*[8]	2018	Iran	cross- sectional	New Tom Vgi	15*15	110	3	327	7-65	…	…	…	…	…	…	…	…	…	…	76.7
9	6	Bhalchim *et al.*[1]	2018	India	cross-sectional	Planmeca Promax 3D	…	…	…	200	10-73	12.5	44	56	24	76	…	…	…	…	…	…

10	6	Borahan *et al.*[6]	2018	Turkey	cross-sectional	Planmeca Promax 3D	…	…	…	300	18-85	32.7	57.1	42.9	51	49	…	…	…	…	…	…
11	6	Jangam *et al.*[20]	2017	India	cross-sectional	Kodak CS 9300	…	76-100	12	62	19-65	40.3	72	28	59.4	40.6	…	…	…	…	…	…
12	7	Shokri *et al.*[12]	2015	Iran	cross-sectional	New Tom 3G volume	9*12	110	1.1	377	8-73	15.6	69.5	30.5	15.3	84.7	…	…	…	…	…	…
13	8	Ilguy *et al.*[4]	2015	Turkey	cross-sectional	ILUMA	19*24	120	3.8	111	17-81	65.8	42.5	57.5	14.3	86.1	11.7	76.9	23.1	75	25	…
14	7	Mosavat *et al.*[19]	2015	Iran	cross-sectional	Alphard-3030	…	80	5	239	18-81	21.3	68.6	31.4	47.1	52.9	5.9	57.1	42.9	57.1	42.9	…
15	5	Demirel *et al.*[5]	2014	Turkey	cross-sectional	…	…	…	…	250	15-82	…	…	…	…	…	…	…	…	…	…	67.6
16	7	Delilbasi *et al.*[18]	2013	Turkey	cross-sectional	Newtom 3G	9*9	…	…	825	18-91	2.54	66.7	33.3	25	75	…	…	…	…	…	…
17	6	Ladeira *et al.*[21]	2013	Brazil	cross- sectional	Classic i-CAT	…	120	8	658	11-85	21.3	54.3	45.7	3.4	96.6	38.3	42.5	57.5	0.2	99.8	…
18	7	Miloglu *et al.*[13]	2011	Turkey	cross-sectional	NewTom FP OR-DVT 9000	13*17	110	15	514	4-85	8	75.6	24.4	41.5	58.5	…	…	…	…	…	…
19	7	Miloglu *et al.*[17]	2010	Turkey	cross-sectional	NewTom FP OR-DVT 9000	13*17	110	15	603	6-24	6.47	59	41	42.2	57.8	…	…	…	…	…	…

Concerning the results of CBCT images, some articles had only reported the prevalence of PAT [1, 6, 12, 13, 17, 18, 20], some had reported the prevalence of PGF as well [3, 4, 7, 10, 11, 16, 19, 21], and two articles had reported the overall prevalence of pneumatization in the TMJ regardless of the anatomic components [2, 8]. Since in the present study, the prevalence was studied regarding the anatomic components of TMJ, the outcomes of these two studies that reported the overall prevalence and consequently very high were not included in the meta-analysis. In Lacin's study [2], the prevalence of pneumatization was reported at 84.9%, and in a study by Khojastehpour *et al*. [8], this value was reported at 76.7%.

The outcomes of available articles have classified the prevalence of PAT and PGF into unilateral and bilateral regarding the laterality, and into unilocular and multilocular concerning the radiographic view. Two articles did not the possibility of accommodation of outcomes in the mentioned subgroups regarding the application of different classification systems for pneumatization [5, 9]. In most of the articles, Pneumatization in the AT and GF were evaluated separately based on Tyndall and Matteson's classification and radiologist diagnosis based on their skills and authority on anatomic regions in radiographic images; however, these two articles had used Zamaninaser *et al.* classification [9], and Al-Faleh and Ibrahim [5] classification respectively in order to locate the pneumatization more accurately; hence, comparing their results to other articles was impossible. Therefore, the overall prevalence of pneumatization (based on studied TMJs) in all groups of these classifications (Prevalence of PAT and/or PGF) was reported at 88% in Nadaes's study [9], and this value was 67.6% in a study by Demirel and colleagues [5].

Data Synthesis and Meta-Analysis

Pneumatization of the Articular Tubercle (PAT)

The results of the meta-analysis regarding the prevalence of PAT (among the studied persons) are shown in **Figure 2**. Accordingly, the effect size of 0.24 (95% CI: 0.18, 0.31) was calculated and heterogeneity was detected among the articles (I^2=98.62%; P-heterogeneity <0.001). Sensitivity analysis showed that the estimated prevalence of PAT is not affected by a specific study. Based on the results of Begg's test and Egger's test, publication bias was detected (Begg's test P = 0.015, Egger's test P < 0.001). Therefore, the prevalence of PAT was estimated again from the Trim and Fill method (0.240, 95% CI: 0.175, 0.305).

The prevalence of PAT (among the studied TMJs) was calculated at 0.19 (95% CI: 0.11, 0.27) and heterogeneity was detected among the articles (I^2=99.41%; P-heterogeneity <0.001) (**Table 2**). Sensitivity analysis showed that the estimated prevalence of PAT is not affected by a specific study. Begg's test showed no publication bias (Begg's test P = 0.099); however, based on Egger's test results which are superior to Begg's test in this regard, publication bias was detected (Egger's test P = 0.022). Therefore, The Trim and Fill method was used for re-estimation of the prevalence of PAT (0.194, 95% CI: 0.114, 0.275).

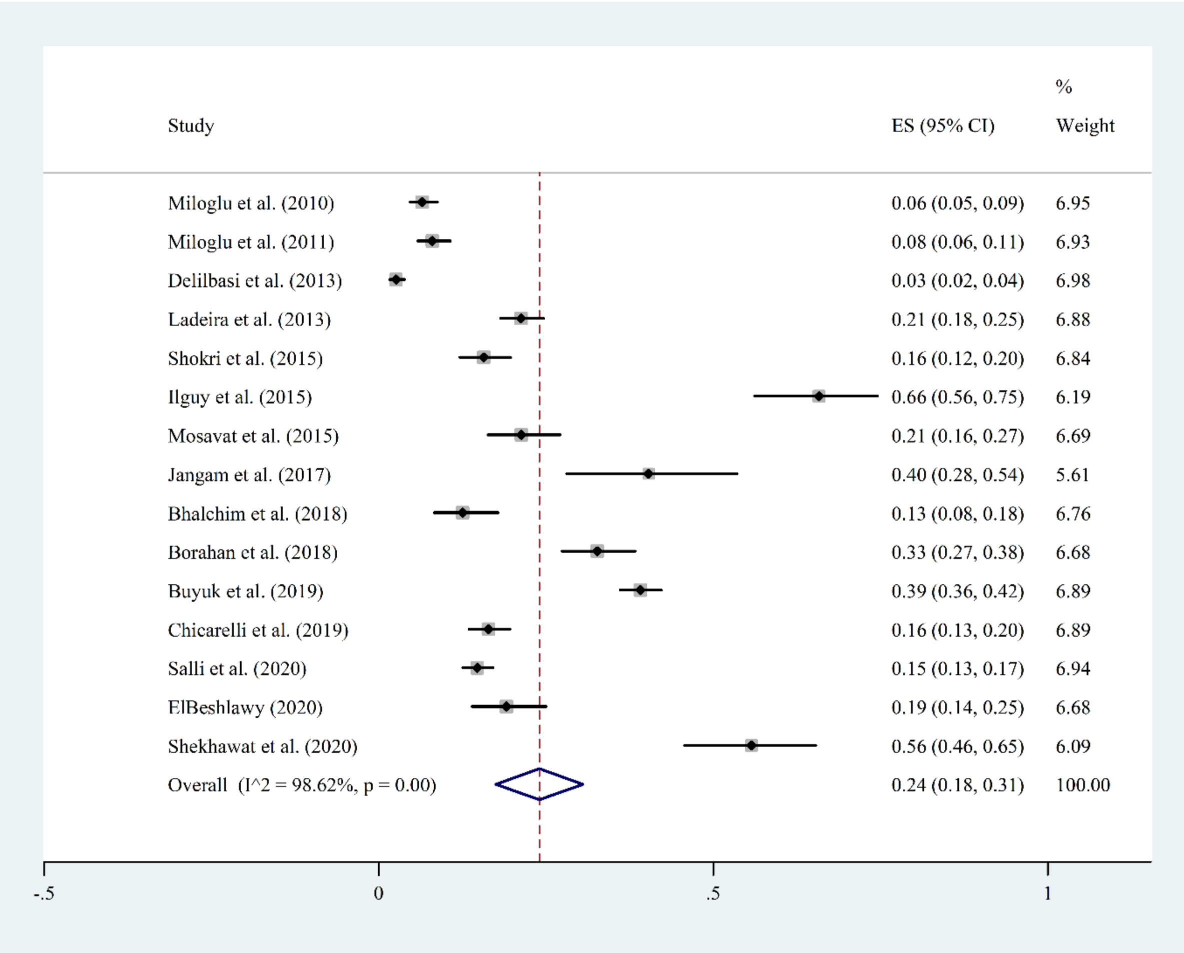

Figure 2. Forest Plot of the prevalence of PAT (regarding the studied Persons)

Table 2. Summary of the results of PAT.

Studied statistical index	95% CI	Heterogeneity	Egger's test P	Begg's test P

	Number of included articles	ES		P-value	I^2		
Prevalence of PAT (among the studied persons)	15	0.24	0.18-0.31	<0.001	98.62%	<0.001	0.015
Prevalence of PAT (among the studied TMJs)	7	0.19	0.11-0.27	<0.001	99.41%	0.022	0.099
Prevalence of PAT in men (among the studied persons)	11	0.19	0.12-0.26	<0.001	96.81%	0.007	0.036
Prevalence of PAT in women (among the studied persons)	11	0.18	0.11-0.25	<0.001	97.51%	0.020	0.186
Prevalence of unilateral PAT (among the studied persons)	14	0.60	0.55-0.64	<0.001	59.47%	0.314	0.622
Prevalence of bilateral PAT (among the studied persons)	14	0.40	0.36-0.45	<0.001	59.47%	0.314	0.622
Prevalence of the unilocular pattern of PAT (among the studied persons)	14	0.30	0.21-0.40	<0.001	95.88%	0.003	0.112
Prevalence of the multilocular pattern of PAT (among the studied persons)	14	0.70	0.60-0.79	<0.001	95.88%	0.003	0.112

Based on the results of this study, the prevalence of PAT among the studied persons was calculated at 24% which is significant. This index was also assessed concerning the studied TMJs and a lower rate of 19% was reported.

The results of the meta-analysis regarding the prevalence of PAT in men (among the studied persons) are shown in **Table 2**. Accordingly, this value is calculated at 0.19 (95% CI: 0.12, 0.26), and heterogeneity was detected among the articles (I^2=96.81%; P-heterogeneity <0.001). Sensitivity analysis showed that the estimated prevalence of PAT in men is not affected by a specific study. Based on the results of Begg's test and Egger's test tests, publication bias was detected (Begg's test P = 0.036, Egger's test P = 0.007), and Therefore the Trim and Fill method was used for re-estimation of the prevalence of PAT in men (0.190, 95% CI: 0.122, 0.258).

The results of the meta-analysis regarding the prevalence of PAT in women (among the studied persons) are shown in **Table 2**. Accordingly, this value is calculated at 0.18 (95% CI: 0.11, 0.25) and heterogeneity was detected among the articles (I^2=97.51%; P-heterogeneity <0.001). Sensitivity analysis showed that the estimated prevalence of PAT in women is not affected by a specific study. Begg's test showed no publication bias (Begg's test P = 0.186); however, based on Egger's test result, publication bias was detected (Egger's test P = 0.020). Therefore, the Trim and Fill method was used for re-estimation of the prevalence of PAT in women (0.180, 95% CI: 0.107, 0.253).

Based on the results of this study, the prevalence of PAT in men (among the studied persons) was 19%, which was slightly higher than this value in women (18%).

The results of the meta-analysis regarding the prevalence of unilateral PAT (among the studied persons) are shown in **Table 2**. Accordingly, this value is calculated at 0.60 (95% CI: 0.55, 0.64) and heterogeneity was detected among the articles (I^2=59.47%; P-heterogeneity <0.001). Sensitivity analysis showed that the estimated prevalence of unilateral PAT was not affected by a specific study. Based on the results of Begg's test and Egger's test, publication bias was not detected (Begg's test P = 0.622, Egger's test P = 0.314).

The results of the meta-analysis regarding the prevalence of bilateral PAT (among the studied persons) are shown in **Table 2**. Accordingly, this value is calculated at 0.40 (95% CI: 0.36, 0.45) and heterogeneity was detected among the articles (I^2=59.47%; P-heterogeneity <0.001). Sensitivity analysis showed that the estimated prevalence of bilateral PAT was not affected by a specific study. Based on the results of Begg's test and Egger's test, publication bias was not detected (Begg's test P = 0.622, Egger's test P = 0.314).

According to the results, the unilateral prevalence of PAT (60%) is higher than bilateral PAT (40%).

The results of the meta-analysis regarding the prevalence of unilocular patterns of PAT (among the studied persons) are shown in **Table 2**. Accordingly, this value is calculated at 0.30 (95% CI: 0.21, 0.40) and heterogeneity was detected among the articles (I^2=95.88%; P-heterogeneity <0.001). Sensitivity analysis showed that the estimated prevalence of the unilocular pattern of PAT was not affected by a specific study. No publication bias was reported based on the results of the Begg's test (Begg's test P = 0.112); however, the Egger's test showed publication bias (Egger's test P = 0.003). Therefore, the Trim and Fill method was used for re-estimation of the prevalence of the unilocular pattern of PAT, and similar results were achieved.

The results of the meta-analysis regarding the prevalence of multilocular patterns of PAT (among the studied persons) are shown in **Table 2**. Accordingly, this value is calculated at 0.70 (95% CI: 0.60, 0.79) and heterogeneity was detected among the articles (I^2=95.88%; P-heterogeneity <0.001). Sensitivity analysis showed that the estimated prevalence of the multilocular pattern of PAT was not affected by a specific study. No publication bias was reported based on the results of the Begg's test (Begg's test P = 0.112); however, the Egger's test showed publication bias (Egger's test P = 0.003). Therefore, the Trim and Fill method was used for re-estimation of the prevalence of the multilocular pattern of PAT, and similar results were achieved.

According to the results, the prevalence of the multilocular pattern of PAT (70%) is higher than the unilocular pattern of PAT (30%).

Pneumatization of the Glenoid Fossa (PGF)

The results of the meta-analysis regarding the prevalence of PGF (among the studied persons) are shown in **Figure 3**. Accordingly, the effect size of 0.31 (95% CI: 0.17, 0.46) was calculated and heterogeneity was detected among the articles (I^2=99.09%; P-heterogeneity <0.001). Sensitivity analysis showed that the estimated prevalence of PGF is not affected by a specific study. Based on the results of Begg's test and Egger's test, publication bias was not detected (Begg's test P = 1.000, Egger's test P = 0.765).

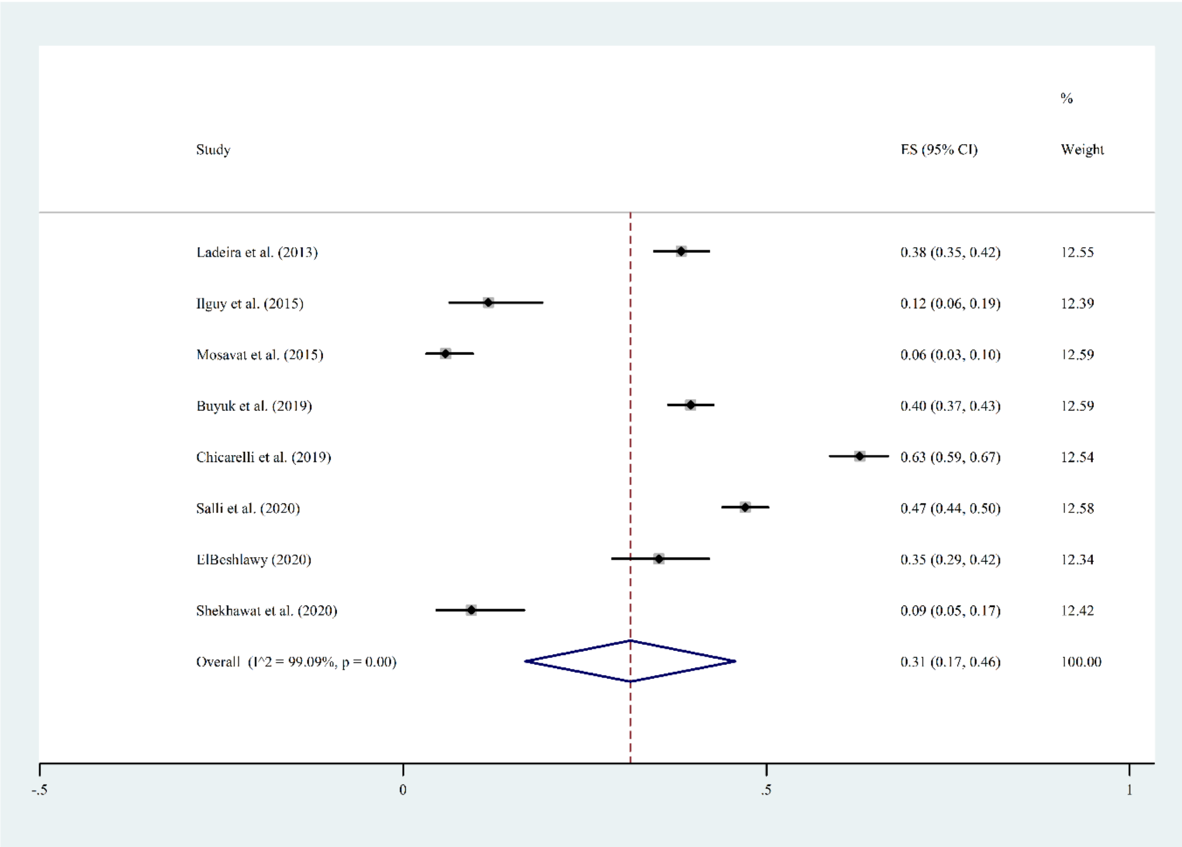

Figure 3. Forest Plot of the prevalence of PGF (regarding the studied persons)

The prevalence of PGF (among the studied TMJs) was calculated as 0.30 (95% CI: 0.15, 0.45) and heterogeneity was detected among the articles (I^2=99.24%; P-heterogeneity <0.001) (**Table 3**). Sensitivity analysis showed that the estimated prevalence of PGF is not affected by a specific study. Begg's test and Egger's test showed no publication bias (Begg's test P = 1.000, Egger's test P = 0.808).

Table 3. Summary of the results of PGF.

Studied statistical index	Number of included studies	ES	95% CI	Heterogeneity P-value	Heterogeneity I^2	Egger's test P	Begg's test P
Prevalence of PGF (among the studied persons)	8	0.31	0.17-0.46	<0.001	99.09%	0.765	1.000
Prevalence of PGF (among the studied TMJs)	4	0.30	0.15-0.45	<0.001	99.24%	0.808	1.000
Prevalence of PGF in men (among the studied persons)	5	0.28	0.11-0.46	<0.001	97.89%	0.755	0.327
Prevalence of PGF in women (among the studied persons)	5	0.27	0.08-0.46	<0.001	98.62%	0.957	1.000
Prevalence of unilateral PGF (among the studied persons)	8	0.47	0.39-0.55	<0.001	88.06%	0.091	0.216

Prevalence of bilateral PGF (among the studied persons)	8	0.53	0.45-0.61	<0.001	88.06%	0.091	0.216
Prevalence of unilocular pattern of PGF (among the studied persons)	7	0.19	0.12-0.25	<0.001	97.68%	0.001	0.176
Prevalence of multilocular pattern of PGF (among the studied persons)	7	0.81	0.75-0.88	<0.001	97.68%	0.001	0.176

Based on the results of this study, the prevalence of PGF regarding the studied persons was calculated at 31% which is a higher rate than the prevalence of PAT and a significant amount. This index was also assessed concerning the studied TMJs and a slightly lower rate of 30% was calculated.

The results of the meta-analysis regarding the prevalence of PGF in men (among the studied persons) are shown in **Table 3**. Accordingly, this value is calculated at 0.28 (95% CI: 0.11, 0.46) and heterogeneity was detected among the articles (I^2=97.89%; P-heterogeneity <0.001). Sensitivity analysis showed that the estimated prevalence of PGF in men is not affected by a specific study. Based on the results of Begg's test and Egger's test, publication bias was not detected (Begg's test P = 0.327, Egger's test P = 0.755).

The results of the meta-analysis regarding the prevalence of PGF in women (among the studied persons) are shown in **Table 3**. Accordingly, this value is calculated at 0.27 (95% CI: 0.08, 0.46) and heterogeneity was detected among the articles (I^2=98.62%; P-heterogeneity <0.001). Sensitivity analysis showed that the estimated prevalence of PGF in women is not affected by a specific study. Based on the results of Begg's test and Egger's test, publication bias was not detected (Begg's test P = 1.000, Egger's test P = 0.957).

Based on the results of this study, the prevalence of PGF in men (among the studied persons) was 28%, which was slightly higher than this value in women (27%).

The results of the meta-analysis regarding the prevalence of unilateral PGF (among the studied persons) are shown in **Table 3**. Accordingly, this value is calculated at 0.47 (95% CI: 0.39, 0.55) and heterogeneity was detected among the articles (I^2=88.06%; P-heterogeneity <0.001). Sensitivity analysis showed that the estimated prevalence of unilateral PGF was not affected by a specific study. Based on the results of Begg's test and Egger's test, publication bias was not detected (Begg's test P = 0.216, Egger's test P = 0.091).

The results of the meta-analysis regarding the prevalence of bilateral PGF (among the studied persons) are shown in **Table 3**. Accordingly, this value is calculated at 0.53 (95% CI: 0.45, 0.61) and heterogeneity was detected among the articles (I^2=88.06%; P-heterogeneity <0.001). Sensitivity analysis showed that the estimated prevalence of bilateral PGF was not affected by a specific study. Based on the results of Begg's test and Egger's test, publication bias was not detected (Begg's test P = 0.216, Egger's test P = 0.091).

According to the results, the bilateral prevalence of PGF (53%) is higher than unilateral PGF (47%).

The results of the meta-analysis regarding the prevalence of the unilocular pattern of PGF (among the studied persons) are shown in **Table 3**. Accordingly, this value is calculated at 0.19 (95% CI: 0.12, 0.25) and heterogeneity was detected among the articles (I^2=97.68%; P-heterogeneity <0.001). Sensitivity analysis showed that the estimated prevalence of the unilocular pattern of PGF was not affected by a specific study. No publication bias was reported based on the results of the Begg's test (Begg's test P = 0.176); however, the Egger's test showed publication bias (Egger's test P = 0.001). Therefore, the Trim and Fill method was used for re-estimation of the prevalence of the unilocular pattern of PGF, and a similar result was achieved.

The results of the meta-analysis regarding the prevalence of the multilocular pattern of PGF (among the studied persons) are shown in **Table 3**. Accordingly, this value is calculated at 0.81 (95% CI: 0.75, 0.88) and heterogeneity was detected among the articles (I^2=97.68%; P-heterogeneity<0.001). Sensitivity analysis showed that the estimated prevalence of the multilocular patterns of PGF was not affected by a specific study. No publication bias was reported based on the results of the Begg's test (Begg's test P = 0.176); however, the Egger's test showed publication bias (Egger's test P = 0.001). Therefore, the Trim and Fill method was used for re-estimation of the prevalence of the multilocular pattern of PGF, and a similar result was achieved.

According to the results, the prevalence of the multilocular pattern of PGF (81%) was significantly higher than the unilocular pattern of PAT (19%).

The present systematic review study evaluated the available evidence regarding the prevalence of pneumatization of the components of TMJ and its pattern through CBCT images. It is worth noting that no systematic review and meta-analysis were performed beforehand. Summarizing the available data is considered the basis of accurate anatomic knowledge in this regard. Therefore, the outcomes of the present study reveal the importance of including pneumatization in radiographic reports written by oral and maxillofacial radiologists; and also help the surgeon in selecting pre-operative precautionary interventions and choosing the ideal surgical approach in the TMJ area to minimize the risk of complications. Moreover, having knowledge about these structures is beneficial for interpreting the radiographic images and provides valuable data for comprehension of the etiology, grade of extension, and differential diagnosis of pathologic conditions in this region [21]. These air-filled cavities may resemble similar characteristics as other pathological lesions in this area including hemangioma, aneurysmal bone cyst, giant-cell tumors, vascular malformations, eosinophilic granuloma, metastatic lesions, and initial stages of fibrous dysplasia [3, 10]. It is worth noting that all of the above-mentioned lesions have a destructive nature and the ability to expand, and therefore, they can have clinical manifestations; while pneumatization is asymptomatic and radiographically is considered a non-expansile and non-destructive defect with well-defined borders and needs no treatment [2, 10, 11]. If asymptomatic unilateral pneumatization is accidentally detected in the AT, it should be monitored to determine the actual nature of the lesion over time [13].

Since PAT and PGF detected in radiographic images are clinically asymptomatic, they were considered secondary random findings in the past [10]. Nowadays, prevalence studies, especially those using three-dimensional radiographic modalities including CT or CBCT, are considered the gold standard evidence for evaluation of pneumatic air cavities of the skull as they provide valuable data for better perception of nature and variable characteristics of their rare defects [10].

Temporal bone pneumatization is affected by individual diversities and multifactorial etiology [9]; therefore, variety in its prevalence and pattern is considered normal. On the other hand, contradictory results in the available articles can be explained by 1- ethnic diversification, 2- variety in the studied samples (including sample size and selected age group), 3- differences in the CBCT units and technical parameters (FOV, voxel size, artifacts, and design of the detector) that can affect the quality of the final image, image receiving protocols, 4- and the skill of the radiologist as an observer [9, 11]. The impact of these factors is unavoidable in radiologic studies. For a summation of the various results of different studies, quantitative summarizing the data using meta-analysis can be helpful. Finally, in the present study with 15 selected articles, the prevalence of PAT among the studied participants (overall 6792 persons) was reported at 24%; in the analysis of 8 articles the prevalence of PGF (overall 3911 persons), this value was estimated at 31%. Generally speaking, evaluation of the prevalence of PGF was studied less than PAT mainly because assessment of the GF became possible with the appearance of CBCT and therefore newer articles have evaluated this anatomic region.

Articles have also reported the prevalence of PAT and PGF among studied TMJs which were estimated at 19% and 30% respectively; these measures are slightly smaller than the prevalence of these indexes when calculated based on the studied persons.

Advances in 3-D imaging have led to a higher reported prevalence of pneumatization in comparison to the previously reported prevalence in the studies based on 2-D imaging (1.0-6.2%) [9]. Panoramic imaging is two-dimensional and has inherent problems including wide focal zone, superimposition of the adjacent structures in this region, and magnification or distortion; all of which make panoramic view inadequate for demonstrating the anatomic landmarks around the TMJ; besides, medial components of the TMJ cannot be accurately assessed by this imaging modality [2, 11, 16]. Rezende Barbosa and colleagues showed that the panoramic view in comparison to CBCT has medium to low accuracy for diagnosis of the pneumatization of the temporal bone [11]. Hence, the high prevalence of pneumatization in the present study is explicable due to the fact that the modality used in articles was CBCT.

Furthermore, it is worth noting that regarding the outcomes of the meta-analysis, the prevalence of PGF was reported to be greater than PAT (31% vs. 24%). Since pneumatization of the squamous, petromastoid, and tympanic parts can be extended to the AT [3], a more approximate location of GF to these structures in comparison to AT, can be responsible for a higher rate of extension of air-filled cavities to this component and may be a probable reason for the higher prevalence of pneumatization in GF.

Concerning the prevalence of pneumatization based on gender, there is a lot of heterogeneity among the included articles; nevertheless, randomized models of the present meta-analysis showed an insignificant difference between the two genders and therefore there was no gender tendency in the prevalence of this phenomenon. Based on the studied persons, the prevalence of PAT was reported at 19% in men and 18% in women; also, the prevalence of PGF in men was reported at 28%, and in women was 27%. The male-to-female ratio for PAT was 1.06:1 and this measure was 1.04:1 for PGF. In many of the articles, it was explained that the onset of pneumatization is in the puberty period or the growth stage after delivery; as puberty occurs earlier in females, pneumatization in women is biologically more developed and obvious in comparison to men in the same age [3,10). In case the evaluation is limited to adolescents, more air cavities may be expected in women rather than men; however, since the studied persons had a wide age range and a summation of the results was done, no significant difference was noted between men and women. In fact, in the process of life, this phenomenon is considered a physiologic event that can occur in all individuals and is not related to gender.

In the prevalence evaluation of pneumatization regarding laterality, unilateral PAT was higher than bilateral prevalence (60% vs. 40%) with the unilateral: bilateral ratio of 1.5:1. In the GF region, results were inversed which means the prevalence of bilateral PGF was higher than unilateral defect (53% vs. 47%) (Bilateral: unilateral ratio of 1.3:1). By gender, unilateral PAT in men was more prevalent than women (61% vs. 54%); while bilateral PAT was more common in women rather than men (46% vs. 39%). These values are in reverse order concerning PGF which means unilateral PGF was more prevalent in women than men (54% vs. 44%); while bilateral PGF is more common in men in comparison to women (55% vs. 46%). In unilateral cases, both PAT (61% vs. 39%) and PGF (65% vs. 35%) were more prevalent on the left side in comparison to the right side. Moreover, PAT on the right side was more prevalent in women; while PAT on the left side was more commonly seen in men. Regarding PGF, adequate data were not available for the calculation of the prevalence in this regard. Concerning phenomena with anatomic origin including the pneumatization in TMJ complex, comparison to the contralateral side usually reveals the same condition on radiographic evaluation; in other words, anatomic variations are usually bilateral. Peripheral factors however can affect these conditions and can impose localized changes in their presentation and therefore they may show asymmetry. For example, in a few articles, a relationship between malocclusion and the prevalence of pneumatization of temporal components of TMJ is assessed and it was shown that GF is significantly affected by peripheral changes like type and direction of forces transferred to the TMJ complex [11]. They suggested that in the Class I occlusal relationship, no abnormal force is transferred to the TMJ; hence, bone remodeling is prevented and extension of the pneumatization is accelerated. Nonetheless, this is a theoretical statement [11]. Hence, occlusal changes and habits like unilateral chewing can lead to a higher load on one side, or the distribution of load may be symmetrical and play a major role in the development of laterality patterns. This issue needs a more comprehensive study. Moreover, genetic factors should be considered. Still, past studies have not found a specific predisposing factor for the unilateral or bilateral development of pneumatization; also, there is no mechanism explaining the laterality pattern of pneumatization [10].

It is believed that panoramic imaging is inadequate for studying the type of pneumatization due to its low resolution (limited ability to show details) and superimposition of adjacent structures in this region [3]. By introducing 3-D imaging modalities into the research, the internal structure of pneumatization was noticed and classified more accurately and correctly owing to its higher spatial resolution that allows for the diagnosis of delicate anatomic structures including thin septa in radiolucent areas. Evaluating the prevalence of pneumatization regarding locularity, the multilocular pattern of PAT (70%) was more prevalent than its unilocular pattern (30%); similarly, the multilocular pattern of PGF (81%) was significantly more prevalent than its unilocular pattern (19%). By gender, the unilocular pattern of PAT was more common in men than women (33% vs. 28%); while the prevalence of the multilocular pattern of PAT was higher in women in comparison to men (72% vs. 67%). For PGF available data was inadequate. It seems that these patterns appear during the developmental process and regarding its histopathologic structure; still, there is no approved reason recommended to explain the high prevalence of multilocular patterns in comparison to the unilocular structure.

It is suggested that in future studies etiology, mechanism of development, and predisposing factors that may be related to the laterality and locularity pattern of temporal components of TMJs be studied.

Conclusion

Concerning the significant prevalence of PAT (24%) and PGF (31%) that was calculated by using CBCT images in this review, pneumatization of the temporal components of TMJ is considered an important normal variation that should be included in writing a radiographic report by oral and maxillofacial radiologists. In addition, CBCT is considered a valuable diagnostic tool for determining the pattern and location of pneumatization of the temporal bone and its relationship to the adjacent structures before any surgical intervention in the TMJ area.

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References

1. Bhalchim SG, Jugade SC, Ramaswami E, Gogri AA, Kadam SG UH. Prevalence of Pneumatized Articular Tubercle Using Panoramic Radiography and Cone Beam-Computed Tomography: A Retrospective Study. Contemp Clin Dent. 2018;9:S221–6.

2. Laçin N, Yalçın M. Evaluation of pneumatic cavities surrounding temporomandibular joint by cone beam computed tomography. J Stomatol Oral Maxillofac Surg. 2020;121(3):238–41.

3. Şallı GA, Özcan İ, Pekiner FN. Prevalence of pneumatization of the articular eminence and glenoid fossa viewed on cone-beam computed tomography examinations in a Turkish sample. Oral Radiol. 2020;36(1):40–6.

4. İlgüy M, Dölekoğlu S, Fişekçioğlu E, Ersan N, İlgüy D. Evaluation of pneumatization in the articular eminence and roof of the glenoid fossa with cone-beam computed tomography. Balkan Med J. 2015;32(1):64–8.

5. Demirel O, Kaya E, Üçok CÖ. Evaluation of mastoid pneumatization using cone-beam computed tomography. Oral Radiol. 2014;30(1):92–7.

6. Borahan MO, Sadıkoğlu AN, Ulay G PF. A Preliminary Study of Prevalence and Characteristics of Pneumatization of Articular Eminence on Cone Beam Computed Tomography. Eur J Res Dent. 2018;2(1):6–11.

7. Buyuk C, Gunduz K, Avsever H. Prevalence and characteristics of pneumatizations of the articular eminence and roof of the glenoid fossa on cone-beam computed tomography. Oral Radiol [Internet]. 2019;35(2):171–6. Available from: http://dx.doi.org/10.1007/s11282-018-0334-z

8. Khojastepour L, Paknahad M, Abdalipur V, Paknahad M. Prevalence and Characteristics of Articular Eminence Pneumatization: A Cone-Beam Computed Tomographic Study. J Maxillofac Oral Surg. 2018;17(3):339–44.

9. Nadaes MR, Lagos de Melo LP, Haiter Neto F, Freitas DQ. Correlation between temporomandibular joint temporal component pneumatization and morphology: analysis by cone beam computed tomography. Int J Oral Maxillofac Surg. 2019;48(6):779–86.
10. ElBeshlawy D. CBCT assessment of pneumatization of the articular tubercle and the roof of the glenoid fossa: a retrospective study. Egypt Dent J. 2020;66(3):1553–62.
11. Chicarelli M, Batistussi França VT, Walewski L, Iwaki LCV, Tolentino ES. Temporal bone pneumatization in patients with dentofacial deformities: cone beam computed tomography study. Int J Oral Maxillofac Surg. 2019;48(12):1564–9.
12. Shokri A, Safi Y, Mortazavi H, Baharvand M F-KS. Cone beam computed tomography evaluation of pneumatized articular tubercle. Int J Clin Dent. 2015;8(1):63–71.
13. Miloglu O, Yilmaz AB, Yildirim E, Akgul HM. Pneumatization of the articular eminence on cone beam computed tomography: Prevalence, characteristics and a review of the literature. Dentomaxillofacial Radiol. 2011;40(2):110–4.
14. Moher D, Liberati A, Tetzlaff J AD. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Med. 2009;6(7):e1000097.
15. Yilmaz B Sen, Aksakalli S, Birlik M, Dadasli F, Bolukbasi E, Aytugar E. Occurrence of pneumatic cavities surrounding the temporomandibular joint. J Craniofac Surg. 2015;26(5):1679–82.
16. Shekhawat C, Sobti G, Sundaragiri K, Saxena S, Bhargava P. Evaluation of Pneumatization in Articular Tubercle and Roof of the Glenoid Fossa with Cone-Beam Computed Tomography. RUHS J Heal Sci. 2020;5(2).
17. Miloglu O, Celikoglu M, Yildirim E, Yilmaz AB, Demirtas O. Pneumatized articular eminence in a cohort of orthodontic patients with different sagittal skeletal anomalies: A retrospective cone beam computed tomography study. Oral Radiol. 2010;26(2):82–8.
18. Delilbasi C, Orhan K, Icen M, Aksoy S, Horasan S KKS. Evaluation of articular eminence pneumatization using cone beam computed tomography. Minerva Stomatol. 2013;62(10):349–54.
19. Mosavat F, Ahmadi A. Pneumatized Articular Tubercle and Pneumatized Roof of Glenoid Fossa on Cone Beam Computed Tomography: Prevalence and Characteristics in Selected Iranian Population. J Dentomaxillofacial Radiol Pathol Surg. 2015;4(3):10–4.
20. Jangam DK, Gavit DD, Lohakpure N AA. Evaluation of pneumatization of the articular eminence using cone beam computed tomography imaging. Int J Curr Res. 2017;9(6):52714–7.
21. Ladeira DBS, Barbosa GLR, Nascimento MCC, Cruz AD, Freitas DQ AS. Prevalence and characteristics of pneumatization of the temporal bone evaluated by cone beam computed tomography. Int J Oral Maxillofac Surg. 2013;42(6):771–5.