Acta Scientiarum

http://periodicos.uem.br/ojs
ISSN on-line: 1807-8648
Doi: 10.4025/actascihealthsci.v45i1.58021

ODONTOLOGIA / DENTISTRY ARTICLES

Anatomical *in vivo* study of variations in zygomatic bone: pneumatization and foramina

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ABSTRACT. To determine the prevalence and characteristics of the zygomatic bone pneumatization (ZBP) and the presence and diameter of zygomaticofacial (ZFF), zygomaticoorbital (ZOF) and zygomaticotemporal (ZTF) foramina, correlating the findings with sex, age and facial skeletal pattern using cone beam CT (CBCT). 563 CBCT scans (1,126 ZB) were assessed and the type (uni/multilocular) and laterality of ZBP were determined, in addition to the presence and diameter of ZFF, ZOF and ZTF. Data was correlated with sex, age and facial pattern. 64 patients (11.37%) presented ZBP, with no differences among sex, age, facial patterns and types ($p>0.05$). Most pneumatizations were bilateral (68%; $p<0.01$). ZFF, ZOF and ZTF were detected in 926 (82.2%), 988 (87.7%) and 818 (72.6%) ZB, respectively. Differences were found for ZFF between age groups ($p<0.005$; >21-60 years). No differences were found for diameters ($p>0.05$). There is no relationship between sex, age and facial skeletal pattern with the presence of ZBP. The presence of ZFF was related to the age group. The knowledge about ZB anatomy and its variations is helpful for image interpretation as part of clinical and surgical treatment planning for this region.

Keywords: imaging diagnosis; cone beam computed tomography zygomatic bone.

Received on March 1, 2021.
Accepted on September 8, 2021.

Introduction

The zygomatic bone (ZB) is an anatomical structure that plays an important role in facial harmonization (Nascimento, Visconti, Macedo, Haiter-Neto, & Freitas, 2014) serving as a basis for mini plates to fix dentomaxillofacial fractures(Branemark et al., 2004) and also for skeletal anchoring in the orthopedic correction of Class III malocclusion(Bozkaya, Yüksel, & Bozkayab, 2017). Since it is the second most fractured bone of the face (Covington et al., 1994), its evaluation is crucial in the fields of traumatology, reconstructive and aesthetic plastic surgery (Sharma & Rahul, 2013; Kamburoglu, Büyükkoçak, Acar, & Paksoy, 2017). Three openings emerge from it and allow the passage of nerves with the same names: zygomaticofacial (ZFF), zygomaticoorbital (ZOF) and zygomaticotemporal (ZTF) foramina (Loukas et al., 2008; Coutinho, Martins-Júnior, Campos, Custódio, & Alves e Silva, 2018). Ignorance of the ZB anatomy can lead to injuries such as lesion of the zygomatic-facial nerve or paresthesia in the cheek region (Coutinho et al., 2018). Furthermore, anatomical variations are frequently found and include changes in the number and diameter of foramina and pneumatization (Del Neri, Araujo-Pires, Andreo, Rubira-Bullen, & Ferreira Júnior, 2014; Nascimento et al., 2014; Coutinho et al., 2018).

Pneumatization corresponds to asymptomatic air-filled cavities commonly found in the skull which appears as radiolucent defects similar to mastoid or ethmoid cells, without destruction or enlargement of the cortex (Tyndall & Matteson, 1985; Ladeira, Barbosa, Nascimento, Cruz, & Freitas, 2013; Nascimento et al., 2014; Chicarelli, França, Walewski, Iwaki, & Tolentino, 2019). It represents places of minimal resistance and can facilitate the occurrence of fractures (Ladeira et al., 2013). When neglected, it can be a complicating factor for clinical and surgical procedures in this region. Its recognition is essential for planning, in order to avoid trans and post-surgical problems (Scheuer III et al., 2017; Coutinho et al., 2018).

Few studies addressed the characteristics of ZB (Hwang, Jin, & Hwang, 2007; Loukas et al., 2008; Aksu, Ceri, Arman, Guls, & Tetik, 2009; Kim et al., 2013; Del Neri et al., 2014; Nascimento et al., 2014; Kamburoglu et al., 2017; Ferro, Basyuni, Brassett, & Santhanam, 2017; Coutinho et al., 2018; Iwanaga et al., 2018). Most of them assessed the foramina (Hwang et al., 2007; Loukas et al., 2008; Aksu et al., 2009; Kim et al., 2013; Del Neri et al., 2014; Ferro et al., 2017; Coutinho et al., 2018; Iwanaga et al., 2018) and only one(Nascimento et al., 2014) addressed pneumatization. Also, in most studies the analyzes were performed in dry skulls(Hwang et al., 2007; Loukas et al., 2008; Aksu et al., 2009; Del Neri et al., 2014; Ferro et al., 2017; Coutinho et al., 2018) or fresh cadavers (Iwanaga et al., 2018). Tridimensional exams such as cone beam CT (CBCT) was rarely addressed (Del Neri et al., 2014; Nascimento et al., 2014; Kamburoglu et al., 2017). It is the method of choice for bone evaluation, as it is less expensive and provides lower radiation dose when compared to helical CT (Chicarelli et al., 2019), allowing the visualization of bone components and air cavities without overlapping, exceeding the diagnostic accuracy of radiographs (Ladeira et al., 2013). Then, the aim of this study is to determine the prevalence and characteristics of ZB pneumatization (ZBP) and the presence and the diameter of ZFF, ZOF and ZTF, correlating the findings with sex, age and facial skeletal pattern using CBCT.

Methods

This retrospective and observational study was approved by the Ethics Committee (CAAE #20052919.9.0000.0104) and was developed according to the STROBE initiative (von Elm et al., 2014).

The sample included CBCT scans of 563 patients (1,126 ZB) who underwent examination between 2014 and 2019. Class II and III patients underwent CBCT before orthognathic surgery, for diagnosis and virtual surgical planning. Class I individuals were basically examined for oral or sinus pathologies and implant planning. Exclusion criteria were patients under 18 years, history of congenital craniofacial syndrome, maxillofacial fracture, orthognathic surgery, presence of plaque and / or screws in the ZB, any artifact that prevented the analysis.

Female (n = 329) and male (n = 234) were assessed separately. The sample was divided according to the age in: ≤ 20 (n= 74); 21-40 (n= 270); 41–60 (n= 182); 61-80 (n= 37) years. They were classified according to ANB as: Class I (0°> ANB <4°; n= 207), II (ANB ⩾ 4°; n= 189) and III (ANB ⩽ 0°; n= 167) (Steiner & Hills, 1953).

The exams were obtained by the same radiologist using a Next Generation® i-Cat equipment (Imaging Sciences International, Hatfield, PA, USA), using 120 kVp, 38 mA, 23X17cm field of view (FOV), 300 µm voxel. Images were analyzed using the scanner software (Xoran 3.1.62, Xoran Technologies, Ann Arbor, MI, USA), and the ANB measurements in the InVesalius 3.0® software (Division for Product Development - CTI, Brazil). Before the analysis, a standardized alignment was achieved by rotating the volume to align the Frankfort plane parallel to the horizontal plane in sagittal reconstructions.

The examinations were assessed independently by two observers (calibrated by evaluating 20% of the sample), who were allowed to change image brightness and contrast to ensure optimal viewing. The assessments were performed in duplicate with a 15-days interval. The average between the measurements obtained was used for the final records (quantitative analysis). For the qualitative analysis, when differences were found, consensus was reached with a third blinded observer.

ZBP (hypodense defect in the ZB with no enlargement or cortical destruction) (Nascimento et al., 2014): was evaluated in multiplanar reconstructions, and classified as unilocular (a single radiolucent oval defect with well-defined borders) or multilocular (numerous radiolucent small cavities) (Tyndall & Matteson, 1985; Ladeira et al., 2013; Nascimento et al., 2014; Chicarelli et al., 2019) (Figure 1). The alterations were further classified as unilateral or bilateral.

ZFF, ZOF and ZTF were located and their largest diameters when measured (Figure 2). If any extra foramen were found, the largest was considered the main foramen (Coutinho et al., 2018).

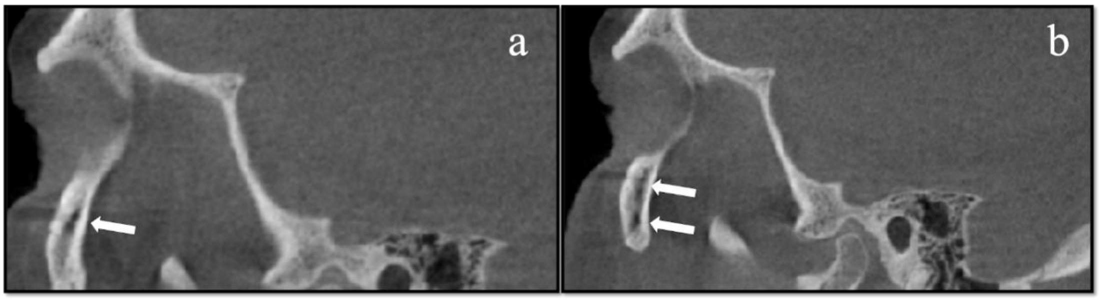

Figure 1. Unilocular (a) and multilocular (b) ZBP (arrows).

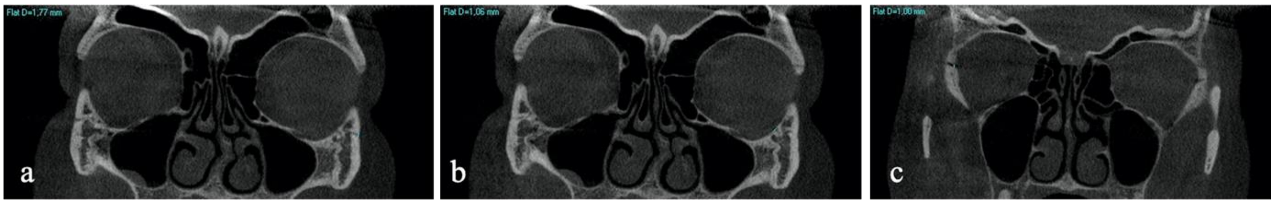

Figure 2. ZFF (a), ZOF (b) and ZTF (c) located and their largest diameters and measured in millimeters.

ZFF, ZOF and ZTF were located and their largest diameters were measured (Figure 2). If any extra foramen were found, the largest was considered the main foramen (Coutinho et al., 2018).

A descriptive analysis was performed to obtain absolute and relative numbers. Chi-square and Fisher's exact tests were used for the relationship between ZBP with sex, age and facial pattern. For the foramina, the chi-square test was used to verify the relationship with these variables. Mann-Whitney U and Kruskal-Wallis tests were used to compare the foramina diameters. The kappa index was used to assess intra- and inter-observer agreement. The significance level was set at $p \leq 0.05$ (IBM SPSS Statistics version 25.0, IBM Corp., Armonk, NY, USA).

Results

The kappa value for intra and inter-observer agreement was almost perfect (>0.85). 64 patients (11.37%) presented ZP with no differences ($p > 0.05$) among sexes, ages and facial patterns. Unilocular and multilocular types were found in 32 individuals (50%). In 44 patients (68.8%) ZBP was bilateral and in 20 (31.3%) it was unilateral ($p < 0.001$) (Table 1).

Table 1. Prevalence of ZBP regarding sex, age and facial pattern.

		Present		Absent		p-value
		N	%	N	%	
Sex	Male	24	37.5	210	42.1	[1]0.484
	Female	40	62.5	289	57.9	
	Total	64	100	499	100	
Age (years)	≤ 20	8	12.5	66	13.2	[2]0.942
	21 - 40	29	45.3	241	48.3	
	41 - 60	22	34.4	160	32.1	
	61 - 80	5	7.8	32	6.4	
	Total	64	100	499	100	
Facial pattern	Class I	24	37.5	183	36.7	[1]0.960
	Class II	22	34.4	167	33.5	
	Class III	18	28.1	149	29.9	
	Total	64	100	499	100	

[1]Chi-square test; [2]Fisher exact test.

ZFF were detected in 926 ZB (82.2%; 467 right and 459 left); ZOF in 988 ZB (87.7%; 487 right and 501 left); ZTF were detected in 818 ZB (72.6%; 412 right and 406 left). In 72 (6.39%) ZB there was more than one foramen. Statistically significant differences were found only for ZFF between the age groups on the right ($p = 0.037$) and left ($p < 0.001$), with the foramen being detected mainly in the 21-40 and 41-60 years-old groups. The mean ZFF, ZOF and ZTF diameters were 1.08 mm (ranging from 0.3- 1.85 mm; 0.3-3 mm; 0.3-2.55 mm) respectively. The relationship of the diameter of ZFF, ZOF and ZTF with sex, age and facial patterns is shown in Table 2. No statistically significant differences were found for the foramina diameters among groups ($p > 0.05$).

Discussion

ZBP represents an area of minimal resistance, facilitating the development of fractures or failure in the implants' osseointegration in this region (Pu et al., 2014). Zygomatic implants emerged as surgical alternatives for patients in whom the conventional implants could not be installed (Branemark et al., 2004) and, for this reason, anatomic variations in ZB should be considered. Likewise, the internal fixation of fractures in this region can be compromised. This justifies the need for anatomical knowledge of the zygomatic region, as well as its variations, in order to carry out an adequate planning for procedures in this area (Pu et al., 2014).

Table 2. Mean values ± standard deviation (sd) for the diameters of ZFF, ZOF and ZTF in right and left sides (mm).

	ZFF					ZOF					ZTF				
	Right diameter		Left diameter			Right diameter		Left diameter			Right diameter		Left diameter		
	Mean	sd	Mean	sd	p-value	Mean	sd	Mean	sd	p-value	Mean	sd	Mean	sd	p-value
Male	1.083	0.285	1.108	0.311	[1]0.346	1.125	0.520	1.087	0.257	[1]0.160	0.782	0.163	0.767	0.188	[1]0.094
Female	1.092	0.265	1.077	0.278	[1]0.336	1.050	0.283	1.085	0.238	[1]0.522	0.791	0.199	0.772	0.174	[1]0.205
Total	[2]0.743		[2]0.721			[2]0.743		[2]0.721			[2]0.743		[2]0.721		
Age (years)															
≤ 20	1.134	0.250	1.109	0.345	[1]0.393	1.127	0.297	1.048	0.248	[1]0.702	0.782	0.193	0.798	0.231	[1]0.382
21 - 40	1.075	0.274	1.105	0.263	[1]0.146	1.093	0.499	1.092	0.237	[1]0.076	0.773	0.187	0.751	0.166	[1]0.054
41 - 60	1.096	0.292	1.063	0.311	[1]0.985	1.041	0.269	1.089	0.267	[1]0.145	0.813	0.182	0.774	0.159	[1]0.210
61 - 80	1.035	0.163	1.088	0.282	[1]0.564	1.098	0.217	1.098	0.212	[1]0.350	0.756	0.161	0.850	0.257	[1]0.242
Total	[3]0.742		[3]0.637			[3]0.566		[3]0.662			[3]0.179		[3]0.069		
Facial pattern															
Class I	1.057	0.247	1.076	0.280	[1]0.834	1.082	0.282	1.109	0.256	[1]0.116	0.767	0.182	0.769	0.190	[1]0.257
Class II	1.088	0.273	1.066	0.289	[1]0.296	1.031	0.234	1.069	0.237	[1]0.055	0.784	0.186	0.766	0.169	[1]0.275
Class III	1.134	0.298	1.133	0.307	[1]0.307	1.141	0.607	1.081	0.245	[1]0.399	0.809	0.187	0.777	0.183	[1]0.174
Total	[3]0.231		[3]0.146			[3]0.131		[3]0.607			[3]0.178		[3]0.409		

[1]Mann-Whitney U test; [2]Kruskal-Wallis test; [3]ANOVA test.

We found ZBP in 11.37% of our sample, a rate higher than that reported by Nascimento et al. (2014), who found the alterations in 3.3% of the evaluated CBCT exams. Technical parameters such as FOV, voxel, artifacts and the design of the detector can influence the image quality, which may explain the differences between the studies (Chicarelli et al., 2019). For this reason we used the same acquisition protocol for all patients. Corroborating our findings, they (Nascimento et al., 2014) showed no differences between sexes and age groups but found statistically differences for laterality. We also detected bilateral cases more frequently. However, they reported only multilocular pneumatizations (Nascimento et al., 2014), while we found the multilocular and unilocular types evenly distributed among the sample. We did not find any other study related to ZBP and the facial pattern was only addressed in our study.

We found no differences regarding pneumatization in different facial patterns. We assumed that in class III patients the poor maxillary development could be compensated, and pneumatization would be more unusual, which has not been proven. A recent study (Chicarelli et al., 2019) evaluated the pneumatization of the temporal bone in different facial patterns and found that pneumatization of the articular eminence was more frequent in class I patients. We agree with the authors that these unprecedented results are valuable since patients with dentofacial disturbances may more often be candidates for maxillary surgery.

CBCT has no superimposition, magnification or distortion (Scarfe, Farman, & Sukovic, 2006) and its resolution allows air cavities as small as 2 mm to be differentiated from bone marrow (Khojastepour, Paknahad, Abdalipur, & Paknahad, 2018). Hence it is considered the gold standard imaging method for assessing pneumatized air spaces in the skull (Rezende Barbosa et al., 2014). The accuracy of diagnosing ZBP is certainly very limited on radiographs. Few studies used CBCT to evaluate the ZB (Del Neri et al., 2014; Nascimento et al., 2014; Kamburoglu et al., 2017). The foramina (ZFF) were addressed in one (Del Neri et al., 2014). The other investigations that evaluated these structures used dry skulls or fresh cadavers (Hwang et al., 2007; Loukas et al., 2008; Aksu et al., 2009; Kim et al., 2013; Del Neri et al., 2014; Ferro et al., 2017; Coutinho et al., 2018; Iwanaga et al., 2018). Most assessed the ZFF and only two investigations addressed the three foramina (Loukas et al., 2008; Coutinho et al., 2018). Therefore, the analysis of all types of ZB foramina using CBCT, which was performed in this study, is unprecedented (Del Neri et al., 2014), determined the presence of ZFF in macerated skulls by physical inspection and compared with CBCT to evaluate the accuracy of the exam in detecting the foramina. ZFF was absent in 19% of ZB and the authors observed that all foramina were detected in CBCT. We did not detect ZFF, ZOF and ZTF in 17.8, 12.3 and 27.4% of cases respectively and no differences were found between sides, corroborating previous investigations (Aksu et al., 2009; Del Neri et al., 2014; Ferro et al., 2017; Coutinho et al., 2018; Iwanaga et al., 2018). We found significant differences only for ZFF when age groups were compared.

Before the study by Del Neri et al. (2014), who evaluated only the ZFF, no investigation had addressed the diameters of the ZB foramina. The authors found a mean diameter of 0.57 mm, using standardized orthodontic steel wires placed into the foramen and an electronic digital caliper (Del Neri et al., 2014). Certainly, the differences in these results when compared to ours (1.08mm) are due to the methodology. In the present *in vivo* study, artifacts caused by the orthodontic wires were not present although motion artifacts may exist. As mentioned, technical parameters may also have influenced (Chicarelli et al., 2019). In addition, the voxel size (0.3mm) limits the measurement of diameters smaller than this value. Anyway, we agree with the authors that the coronal view was the best plane for visualization of the foramina. In addition, corroborating their results, we found no differences in the diameters between sides. If any extra foramen were found, the one with the largest diameter was considered the main foramen (Coutinho et al., 2018). However, only at 6.39% of the ZB extra foramina were detected. Corroborating previous studies (Ferro et al., 2017; Iwanaga et al., 2018), females showed larger foramina, although the differences were not significant. Likewise, corroborating Ferro et al. (2017), differences in diameters were not found between sides. In addition, this is the first study that address the age and facial pattern, with no differences when diameters were compared.

As shown, most studies that measured the ZB foramina diameter of used dry skulls. *In vivo* studies are very scarce. CBCT allows small anatomical structures and their variations to be studied, which includes the small ZB foramina, being a precise tool for this task (Del Neri et al., 2014). In the present study, the use of 0.3 mm voxels was sufficient for the evaluation of these structures, with no need to reduce the voxel size and, consequently, increase the radiation dose to the patient. In addition, the extended FOV, known to be associated with reduced image resolution, did not prevent the foramina from being measured. This is relevant because, in many cases, patients undergoing procedures on the ZB are submitted to CBCT with large FOV.

Conclusion

In conclusion, CBCT is a valuable tool for assessing the anatomy and variations of ZB. Pneumatization was found in 11.37% of the sample, with no differences among sex, age, facial patterns, and type. Most pneumatizations were bilateral. For the ZB foramina, statistically significant differences were found only for ZFF between age groups (> 21-40 and 41-60 years). No differences were found for the foramina diameters among groups. Clinicians should be aware of these alterations, and this knowledge is helpful for image interpretation as part of clinical and surgical treatment planning for this maxillofacial region.

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