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ORIGINAL ARTICLE

The prevalence and location of the posterior superior alveolar artery in the maxillary sinus wall: A preliminary computed-cone beam study

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Abstract The lateral wall of the maxillary sinus is supplied by the posterior superior alveolar artery (PSAA). It may be affected by trauma, pathology, or surgery performed to access or correct any fracture involving the maxillary sinus. This study analysed the prevalence and distance of the PSAA from the floor of the maxillary sinus in selected Southeast Asian patients. *Methods:* This is a cross sectional study conducted using cone-beam computed tomographic images of 83 dentate patients with a mean age of 38.3 years. Results: One hundred sixty-six maxillary sinuses of 54 males and 29 females were evaluated, with PSAA observed in 91.6 % of sinuses. Of the PSAA identified (n = 152), 64.5 % were intraosseous (n = 98), 25.7 % were beneath the sinus membrane (n = 39), and the remaining 15 (9.9 %) were on the external cortex of the lateral sinus wall. The mean distance between PSAA and the lowest point of the sinus floor was 11.44 mm (SD, 3.36). Sixty-four maxillary sinus walls (38.6 %) presented with 2 PSAA branches. The inferior and superior branches were located 6.42 mm (SD, 2.68) and 8.48 mm (SD, 3.56) from the floor of the maxillary sinus, respectively. The mean difference between these 2 branches was 2.25 mm (SD, 1.90). Conclusion: This study confirms the different locations of the PSAA in relation to the lateral wall of the maxillary sinus with no gender influence. Branching of PSAA occurs, and should be highlighted to surgeons.

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1. Introduction

The maxillary sinuses are a pair of paranasal sinuses in the maxillary bone (Dobele et al., 2013). Some surgical procedures done by dentists, maxillofacial surgeons, or head & neck (*ENT*) surgeons may encroach into this cavity. Among these are minor surgeries that include retrieval of displaced roots via the Caldwell-Luc approach, removal of impacted teeth with or without cystic lesion, removal of polyps, and debridement for clearance of sinusitis. Major surgeries include tumour or cancer resection, or a Le Fort I and II osteotomy as in orthognathic surgery. Additionally, the maxillary sinus forms part of the midfacial skeleton that is prone to fracture during trauma, resulting in the need for open reduction and internal fixation to realign the displaced segments (Lim et al., 2017).

The maxillary sinuses undergo pneumatization over time, resulting in decreased height of the alveolar ridge. Placement of posterior implants may consequently intrude into the sinus (Chitsazi et al., 2017). Sinus augmentation surgery is a predictable surgical option to address this lack of posterior bone height and can be done using the lateral window approach (Bathla et al., 2018, Kawakami et al., 2019). However, knowledge of anatomical and structural details and the variations of the maxillary sinuses are essential prior to performing any surgery involving posterior maxilla (Güncü et al., 2011, Bathla et al., 2018, Kawakami et al., 2019). In particular, the blood supply of the region should be considered especially if such procedures are performed in outpatient dental offices (Ilgüy et al., 2013). It has been reported that severing the PSAA may produce conspicuous bleeding requiring ligation to achieve haemostasis (Testori et al., 2010).

The maxillary sinus is supplied by branches of the maxillary artery: the posterior superior alveolar artery (PSAA), the infraorbital artery (IOA), and the sphenopalatine artery (SPA) (Solar et al., 1999, Flanagan 2005). The lateral walls are supplied by the PSAA and IOA. Both arteries give off intraosseous and extraosseous branches and anastomose around the maxillary sinus (Güncü et al., 2011, Bathla et al., 2018). Their courses along the lateral walls can change from intraosseous to extraosseous, and vice versa. Injury to the PSAA during trauma or surgical procedures such as a Le Fort I osteotomy or sinus augmentation surgery could result in severe haemorrhage (Chanavaz 1996, Ella et al., 2008, Ilgüy et al., 2013). Trauma-related haemorrhage can be seen as a fluid level-like opacity in the maxillary sinus using plain radiographs. Haemorrhage could obscure vision during operation and cause perforation of the Schneiderian membrane when performing sinus augmentation; this will complicate the affected operation (Kim et al., 2011). Therefore, a good understanding of basic anatomy and pre-operative assessment of the PSAA is important in avoiding this complication.

To obtain a detailed understanding of the anatomical and functional relationship of the maxillary sinus, 3D-imaging is required. The use of computed tomography (CT) scan has been recommended to search for intraosseous or extraosseous vessels in the lower two thirds of the maxillary sinuses (Ella et al., 2008, Cagici et al., 2009). However, CT has a radiation dose 1.5–12.3 times that of cone beam computed tomography (CBCT) (Ilgüy et al., 2013) and has reported a lower prevalence but showed a wider diameter of the PSAA (Varela-Centelles et al., 2015). CBCT on the other hand is able to provide accurate information on bone morphology and anatomical landmarks at a lower cost and lower radiation (Ludlow and Ivanovic 2008, Pandharbale et al., 2016).

Many studies have evaluated the PSAA's diameter (Güncü et al., 2011, Ilgüy et al., 2013, Maridati et al., 2014) and its prevalence and distance from the alveolar ridge (Solar et al., 1999, Elian et al., 2005, Flanagan 2005, Mardinger et al., 2007, Ella et al., 2008, Hur et al., 2009, Yoshida et al., 2010, Güncü et al., 2011, Jung et al., 2011, Ilgüy et al., 2013, Pandharbale et al., 2016, Chitsazi et al., 2017). However, these studies focused mainly on Caucasian (Solar et al., 1999, Elian et al., 2005, Flanagan 2005, Mardinger et al., 2007, Ella et al., 2008, Hur et al., 2009, Güncü et al., 2011, Ilgüy et al., 2013, Pandharbale et al., 2016, Chitsazi et al., 2017) and selected Asian populations (Yoshida et al., 2010, Jung et al., 2011, Kim et al., 2011), with only one study having included the Southeast Asian population (Laovoravit et al., 2021). The aim of this study is to evaluate the prevalence and location of the PSAA in the maxillary sinus and its distance from the floor of the maxillary sinus in selected Malaysian population using CBCT imaging.

2. Material and methods

This is a radiographic-based study conducted at the Department of Oral and Maxillofacial Clinical Science, Faculty of Dentistry, Kuala Lumpur, Malaysia between 22nd July and 6th September 2019. This study received the relevant Institutional Board of Study approval [DF OS1522/0090(L)]. All indications for radiographic imaging were done in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and the Helsinki Declaration of 1975, as revised in 2008. All CBCT imaging data was obtained for diagnosis and treatment planning and were consented to for research/academic purposes. This cross-sectional observational study observed the STROBE checklist.

The scans of patients who had undergone CBCT examinations for various indications between 2010 and 2015 were screened from the data stored in the CBCT machine (i-CAT Imaging System; Imaging Sciences International Inc. Hatfield, USA). These images were scanned at 120kVp, 3–7 mA, and 20sec, voxel size of 0.3 mm, and field of view with the standard diameter of 16 cm × 13 cm height. CBCT scans with sub-optimal image quality, artefacts, and those showing pathology in the maxilla or previous surgery (i.e., displacement or wiring/plating) were excluded from this study.

Malaysian patients without congenital deformities such as cleft palate and micrognathia were included, whereas subjects with history of trauma to the maxilla (including zygomatic complex fracture), maxillary pathology, poor CBCT quality, and history of surgical intervention to the maxilla were excluded. Sample size was determined with the following formula:

$$Sample\ \ size = \frac{{Z_{1-\alpha/2}}^2\, SD^2}{d^2},$$

where $Z_{1-\alpha}$ = standard normal variate; SD = standard deviation of variable measured; d = absolute error or precision.

Based on SD value of 2.17 from a previous study by (Park et al., 2012), the minimum sample number of 73 would enable detection of morphological differences of the PSAA.

$$Sample\ \ size = \frac{1.96^2 \times 2.17^2}{0.5^2} = 72.3$$

Of the included CBCTs, we assessed the presence (visibility) and location of the posterior superior alveolar artery (PSAA) on coronal images. The PSAA was categorized according to its relationship to the lateral wall of the maxillary sinus; namely intraosseous, beneath the sinus membrane, or on the external cortex of the lateral sinus. Once identified, measurement was performed to obtain the distance from the lowest point of the maxillary sinus floor to the lower margin of the PSAA (Fig. 1). The calliper software of i-Cat Vision (Imaging Sciences International Incorporation Hatfield, USA) was utilised to measure this distance. Measurements were repeated twice by the same researcher (KYA) at a 2-week interval to ensure reproducibility. The training and calibration exercise followed the protocol used by (Lim et al., 2017). The reproducibility of the results was tested using the Bland and Altmann test.

2.1. Statistical analysis

All data was gathered and inserted into Microsoft Excel (Microsoft Corporation, Washington, USA). The data was then transferred to SPSS 26 (IBM, New York, USA) for statistical analysis. Descriptive statistics (mean, variance, range, and standard deviation) were calculated for the variables. Student t-test and χ^2 test were applied to compare the mean values of qualitative variables between males and females. The level of significance for this study was set to $P < 0.05$.

3. Results

Three hundred CBCTs were reviewed. Eighty-three CBCT scans and 166 maxillary sinuses that fulfilled the inclusion criteria were further evaluated. The Bland and Altmann test result was 1.79 %, indicating very good reproducibility.

The mean age of patients was 38.3 years (SD, 13.8) (range: 16–72 years). These CBCTs belonged to 54 male and 29 female patients. Bilateral PSAA was visualised in 72 patients (86.7 %); 46 male (92 PSAA) and 26 female (52 PSAA). Unilateral PSAA was visualised in 8 patients (9.6 %); 6 males and 2 females. Meanwhile, PSAA was not detectable in 3 patients (3.6 %), 2 males and 1 female (Fig. 2). There was no statistical difference between the prevalence of PSAA in males and females (chi-square; $P = 0.60$).

The PSAA was observed in 91.6 % of sinuses (Table 1). Of the PSAA identified (n = 152), it was intraosseous in 64.5 % (n = 98), beneath the sinus membrane in 25.7 % (n = 39) and on the external cortex of the lateral sinus wall in the remaining 15 sides (9.9 %). The intraosseous type of PSAA was significantly prominent in both gender and at both sides (chi-square; P < 0.05). There was a higher percentage of PSAA found beneath the sinus membrane of female (13.8 %) than male (6.5 %); however, this difference was not statistically different (chi-square 2.33; $P = 0.127$).

The mean distance between PSAA and the floor of the maxillary sinus was 11.44 mm (SD, 3.36). This distance ranged from 4.20 mm to 18.00 mm. The longest distance was more than fourfold of the shortest distance. This mean distance amounted to 11.74 mm (SD, 3.45) on the right side and 11.17 mm (SD, 3.29) on the left, which was not statistically different (independent t-test; $P = 0.299$) (Table 2).

Comparing the mean values for both genders, the results of the independent *t-test* also showed no significant differences (Independent t-test; $P = 0.94$). The mean distance from the floor of the sinus to the interior margin of PSAA was 11.46 mm (SD, 3.40) in males and 11.42 mm (SD, 3.34) in females.

Sixty-four maxillary sinus walls (38.6 %) presented with 2 branches of the PSAA in this study. The inferior branch was analysed alongside those seen in sides with single PSAA to arrive at the results described above. When these two arteries were analysed separately, the inferior branch was located 6.42 mm (SD, 2.68) from the floor of the maxillary sinus. Contrastingly, the superior branch was located 8.48 mm (SD, 3.56) from the maxillary sinus floor. The mean difference of these 2 branches was 2.25 mm (SD, 1.90). The range of difference is wide, from 0.30 mm to 10.20 mm, with measurements of 3 mm or less making up slightly more than 80 % of the values.

4. Discussion

Perioperative imaging is essential for the detection of maxillary sinus variations and pathologies (Kawakami et al., 2019). The findings allow for modification of treatment plan and prediction of outcomes of surgery involving the maxillary sinus. The location of blood vessels, particularly the PSAA, must be considered when operating at the lateral wall of the maxillary sinus (Valente 2016). Since the PSAA has been reported to present as 2 branches, gingival and dental, there is increased risk of iatrogenic injury to either or both of them (Monsour and Dudhia 2008, Valente 2016). CBCT is the current recommendation to obtain information on the maxillary sinus (Monsour and Dudhia 2008, Yoshida et al., 2010).

In the present study, the presence and location of PSAA was observed in 91.6 % of the maxillary sinuses and was mainly intraosseous (64.5 %). This success rate of locating the artery was within the range of studies by Shahidi et al. (Shahidi et al., 2016) (93 %), (Laovoravit et al., 2021) (94.6 %), and (Ilgüy et al., 2013) (89.3 %), but higher than those reported by (Güncü et al., 2011) (64.5 %), (Elian et al., 2005) (52.9 %), (Kim et al., 2011) (52 %), and(Jung et al., 2011) (52.8 %). The differences could be due to different imaging modalities (e.g., different generation of machine and viewing system) employed. Besides, studies using CT reported lower prevalence (Kim et al., 2006, Mardinger et al., 2007). In Mardinger et al.'s study, it could be explained by their search for intraosseous PSAA only (Mardinger et al., 2007). The 'absence' of PSAA in this study may be because only larger PSAA can be detected on CBCT, with those lying immediately on either side of the maxillary sinus lateral wall undetectable if they did not indent bone.

According to (Ilgüy et al., 2013), the prevalence of PSAA in different genders remains consistent although they had more female subjects than male, just like the present finding. The distribution according to gender was not balanced in this study, similar to that reported by Ilgüy et al. (2013), Bathla et al. (2018), Kawakami et al. (2019), and Kang et al. (2013). In con-

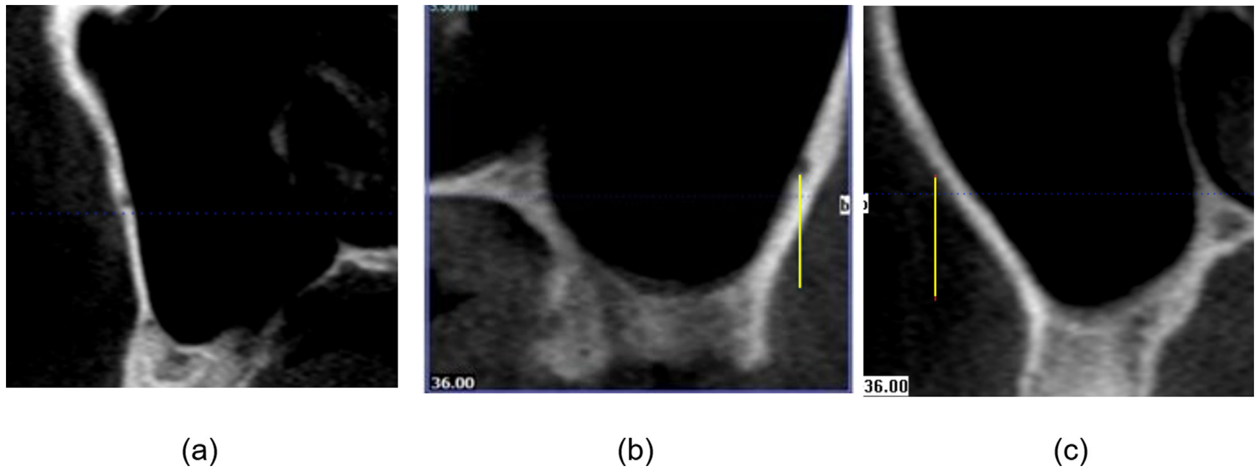

Fig. 1 Yellow line denotes the distance measured in the coronal view of CBCT image using the i-CAT Vision software. A - from the floor of the maxillary sinus to the inferior margin of the PSAA for (a) intraosseous (b) beneath the sinus membrane (c) on the external cortex of the lateral sinus types of PSAA. Image (a) also shows the presence of 2 branches of PSAA.

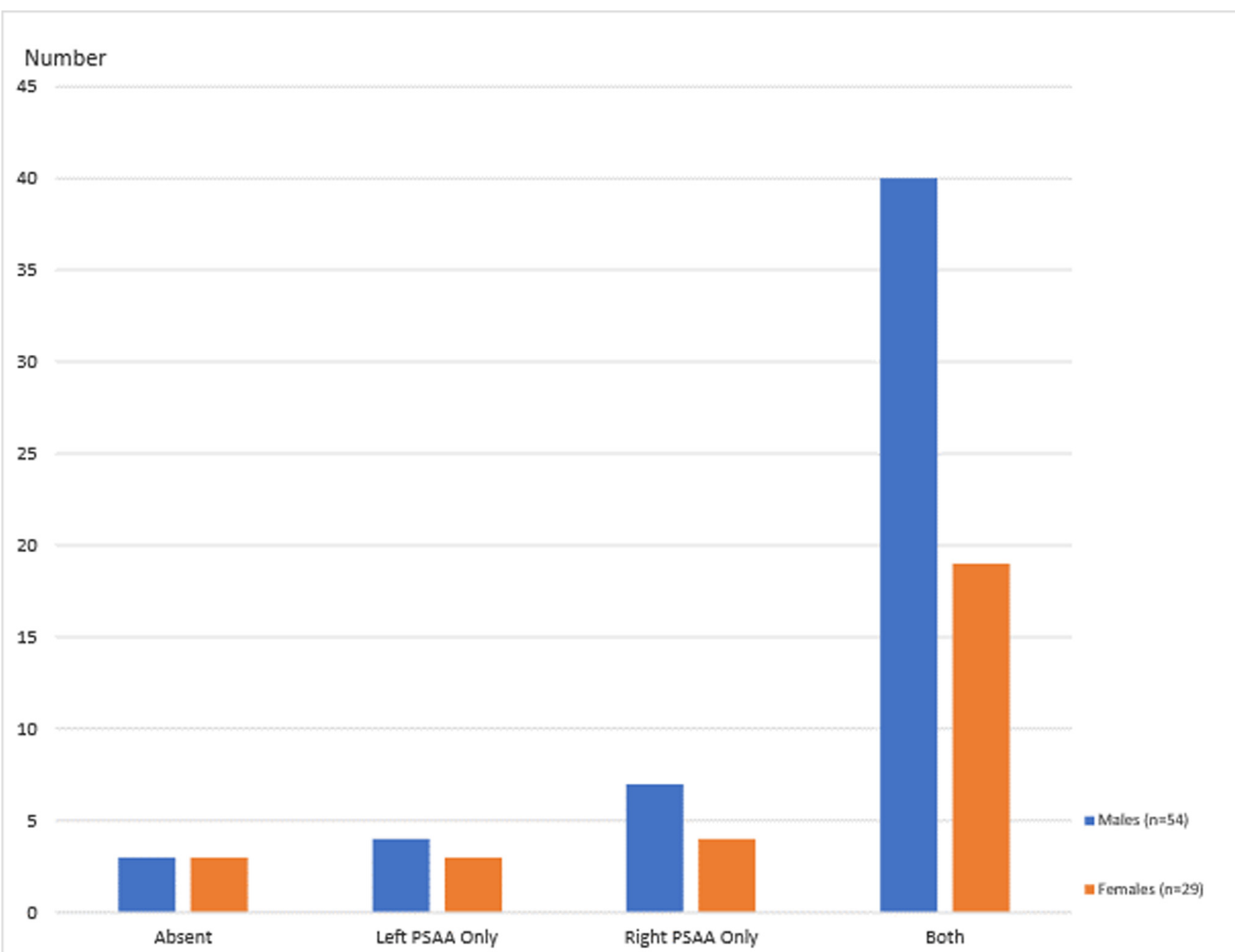

Fig. 2 The prevalence of PSAA according to side and gender.

Table 1 The type (location) of the PSAA based on gender.

Gender	Number (%) Location				
	Not Detectable	Intraosseous	Beneath the sinus membrane	On the external cortex of the lateral sinus wall	Overall
Male	10 (9.3)	66 (61.1 %)	7 (6.5 %)	25 (23.1 %)	108
Female	4 (6.9 %)	32 (55.2 %)	8 (13.8 %)	14 (24.1 %)	58
Total	14 (8.4 %)	98 (59.0 %)	15 (9.0 %)	39 (23.5 %)	166 (100 %)

Table 2 Distance from the inferior margin of the PSAA to the floor of the maxillary sinus.

Side	Gender	
	Male	Female
Left (n = 73)	12.01 (3.29) mm	11.28 (3.71) mm
Mean	11.74 (3.45) mm Range = 4.20–18.0 mm	
Right (n = 79)	10.97 (3.44) mm	11.55 (2.99) mm
Mean	11.17 (3.29) mm Range = 6.00–18.00 mm	

trast, (Kim et al., 2006) found a significant difference between genders. The difference could down to having more male than female subjects in their study (Kim et al., 2006).

The authors used the maxillary sinus floor as a landmark of assessment instead of the alveolar ridge or the cervical of teeth, as has been done in other studies (Kawakami et al., 2019). The crest of the alveolar ridge is an undeniably more useful landmark for the surgeon clinically. However, the crest height varies from patient to patient with different degrees of resorption/ edentulism. Moreover, given the difference in texture and density between the alveolar ridge and maxillary sinus wall, most surgeons would be able to visualize the sinus with its transparent nature. There are at least 13 studies that also measured the distance between the sinus floor and the PSAA (Hur et al., 2009, Jung et al., 2011, Park et al., 2012, Kang et al., 2013, Apostolakis and Bissoon 2014, Watanabe et al., 2014, Yang and Kye 2014, Kawakami et al., 2019, Bedeloğlu and Yalçın, 2020, Karslioglu et al., 2020, Fayek et al., 2021, Laovoravit et al., 2021).

The authors found that the mean distance between the inferior margin of PSAA to the floor of the maxillary sinus was 11.44 mm (range: 4.20–18.00). This result falls within the range reported by Laovoravit et al. (2021). These results are higher than those of previous studies (Pandharbale et al., 2016; Karslioglu et al., 2020; Hur et al., 2009; Jung et al., 2011; Park et al., 2012; Kang et al., 2013; Apostolakis and Bissoon 2014; Watanabe et al., 2014; Yang and Kye 2014; Bedeloğlu and Yalçın, 2020; Fayek et al., 2021). The difference may be attributed to the use of the lower point of the maxillary sinus and the lower border of PSAA as landmarks. Geography and genetic make-up of the patients may also contribute to the current findings as Malaysia is located in Southeast Asia, bordering Thailand (Laovoravit et al., 2021). The shortest distance reported in other reports (0–1.2 mm) (Hur et al., 2009, Apostolakis and Bissoon 2014, Bedeloğlu and Yalçın, 2020) was lower than what we found in this study; our findings are similar to that reported by (Pandharbale et al., 2016) (4.7 mm).

Pandharbale et al. (2016), Yang and Kye (2014), and Tran et al. (2021) reported no statistical differences in the measurements between male and female populations, a finding that we concur with. In contrast, Laovoravit et al. (2021) and Karslioglu et al. (2020) reported that the distance from the artery to the floor of the maxillary sinus was greater in males compared to females. They attributed this to the anatomic variation in the artery position.

Of particular interest is the finding of 2 PSAA branches in 38.6 % of maxillary sinuses. Most studies summarize their results as that of a single branch, although the presence of branches have been acknowledged. (Fayek et al., 2021) reported a prevalence of 8.7 %. Because of this, the current study analysed the inferior branch together with those sides with single PSAA to arrive at a single figure to ease comparison. The inferior branch was located 6.42 mm (SD, 2.68) from the floor of the maxillary sinus, with the second branch located at a mean of 2.25 mm (SD, 1.90) superiorly. The range of differences is wide, from 0.30 mm to 10.20 mm, but the majority (> 80 %) of these branches were 3 mm from each other. This is an important highlight that needs to be kept in mind when performing elective surgeries such as Caldwell-Luc operation, lateral sinus augmentation, and Le Fort I osteotomy for orthognathic surgery. One or both branches of the PSAA may become injured during these procedures, obscuring field of view and lengthening procedure time (Kim et al., 2011). Thorough knowledge of this anatomical variation, location, and between-branch distance are imperative to ensure trouble-free surgery. For instance, these branches can be avoided in Le Fort I osteotomy by planning the cut between them. In lateral sinus augmentation, piezoelectric surgery may be useful to ensure osteotomy cuts can be made adjacent to the branches without severing them.

Limitations of the study include the limited sample size and the inability to stratify analysis into different age groups of patients. Another limitation is the unequal number of patients in gender groups, a problem also exhibited in the study by

Ilgüy et al. (2013), Kawakami et al. (2019), and Kang et al. (2013). The authors recommend that more research be done on larger samples with equal ratios of male to female. Stratification of subjects into different ethnic groups can be useful to determine if there are genetic differences between different ethnicities.

5. Conclusion

This study confirms the different locations of the PSAA in relation to the lateral wall of the maxillary sinus with no gender or side influence. The PSAA presents as 2 branches in almost 40 % of sides, which can be observed using CBCT. To avoid unnecessary complications and improve patient care, 3D-imaging scans shall be performed for surgical procedures involving the maxillary sinus.

CRediT authorship contribution statement

Kar-Yan Ang: Data curation, Formal analysis, Methodology, Writing – review & editing. **Ky-Leigh Ang:** Formal analysis, Methodology, Writing – original draft. **Wei Cheong Ngeow:** Formal analysis, Investigation, Methodology, Supervision, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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