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Cone-beam computed tomography assessment of upper airway dimensions in patients at risk of obstructive sleep apnea identified using STOP-Bang scores

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ABSTRACT

Purpose: The aim of this study was to identify correlations between the STOP-Bang score and upper airway dimensions using cone-beam computed tomography (CBCT) scans.
Materials and Methods: This study included 101 subjects (46 men, 55 women) from dental patients who received CBCT scans from 2014 to 2020. The patients were divided into those with a low obstructive sleep apnoea (OSA) risk (STOP-Bang score <3) and those with an intermediate to high OSA risk (STOP-Bang score ≥ 3), and their upper airway dimensions were then analysed on CBCT scans. Comparisons between the low-risk and intermediate/high-risk groups were conducted using the *t*-test and the Mann-Whitney test. Correlations between the total STOP-Bang score and upper airway dimension parameters were established using Spearman correlation coefficients. *P* values ≤ 0.05 were considered to indicate statistical significance.
Results: Intermediate/high-risk subjects were predominantly male and over 50 years of age, with a higher body mass index. They had significantly longer upper airways, smaller average airway volumes, and smaller widths and antero-posterior dimensions of the narrowest upper airway segment. The total upper airway length was positively correlated with the STOP-Bang score ($r_s = 0.278$). The average volume ($r_s = -0.203$) and width of the narrowest upper airway segment ($r_s = -0.305$) were both negatively correlated with STOP-Bang scores.
Conclusion: Subjects with higher STOP-Bang scores had upper airways that were longer, narrower, and smaller in terms of average volume. CBCT scans taken for dental patients as part of investigative procedures could be correlated with STOP-Bang scores to screen for patients at risk of OSA. ***(Imaging Sci Dent 2021; 51: 439-46)***

KEY WORDS: Body Mass Index; Cone-Beam Computed Tomography; Sleep Apnea, Obstructive

Introduction

Obstructive sleep apnoea (OSA) is a highly prevalent sleep-breathing disturbance, and around 1 billion people are estimated to have this condition globally,[1] affecting all age groups.[2] OSA involves incomplete or total upper respiratory tract collapse resulting in a total halt in breathing or an evident decrease in airflow while sleeping.[3]

The main aetiology of OSA is dysfunction of the genioglossus muscle, leading to weakening of the pharyngeal dilator muscles and, subsequently, reduced expansion forces. Additional hypothesised aetiologies include disorders of the soft tissue, such as tonsillar hypertrophy or macroglossia, as well as skeletal abnormalities (namely, micrognathia and retrognathia).[4]

OSA may be detected through loud snoring, excessive daytime sleepiness and fatigue, and arousal from sleep due to oxygen desaturation.[5] However, due to the low awareness of this condition, more than 80% of individuals with OSA suffer from this disease unnecessarily despite the modern investigations and medical and dental treatments that are available.[6] With the increased incidence of this condition, there may be many patients with undiagnosed OSA who present to dental clinics for routine dental procedures.

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Dentists should have a high index of clinical suspicion and an appropriate understanding of this condition to perform basic screening to identify patients suspected of having OSA during routine dental check-ups.[7]

Cone-beam computed tomography (CBCT) is an imaging modality commonly used in the dental field to capture accurate 3-dimensional views.[8,9] CBCT images are capable of detecting the smaller airway dimensions in OSA patients as compared to healthy subjects.[10] Enciso et al.[11] reported a positive association between a narrow airway width and the presence and severity of OSA using CBCT images. A reduced transverse width of the oropharynx identified using medical computed tomography was also reported in OSA subjects by Mayer and colleagues.[12] Enlarged soft tissues around the airway are also a very important risk factor for OSA.[13] With the increasing use of CBCT in dental clinics in recent years, dentists could use CBCT as a screening modality by assessing the upper pharyngeal airway in 3 dimensions.[14]

Early diagnosis of OSA is usually difficult, as insufficient results and data have been published for the numerous tools that have been proposed, hence disqualifying them as evidence-based screening tools.[15] Many questionnaires have been developed to help diagnose OSA as early and straightforwardly as possible.[16] Studies have shown that out of these questionnaires, in terms of reliability, the STOP-Bang questionnaire surpasses the Berlin questionnaire, the STOP questionnaire, and the Epworth Sleepiness Scale.[17]

The STOP-Bang questionnaire is a straightforward high-performance screening aid that was first developed in 2008.[18] It consisted of 8 binary subjective and demographic variables in accordance to the clinical features of OSA, resulting in a final score ranging from 0 to 8.[1] A score of ≥ 3 as a cut-off was found to be highly sensitive in predicting mild OSA (83.9%), moderate-to-severe OSA (92.9%) and severe OSA (100%).[19] Risk stratification could then be carried out for patients according to their scores.[20]

Increasing levels of expertise in CBCT and the availability of reliable questionnaires have enabled routine screening of dental patients for OSA, so that the diagnosis can be made early and these potential patients can be referred to a medical clinic for further investigation and treatment, if needed, as well as receiving any necessary dental interventions.[21]

It was hypothesised that an individual with a narrower, smaller, and longer upper airway would receive a higher risk score on the STOP-Bang questionnaire.[8,22] This hypothesis was proposed based on fundamental research on the biomechanics of upper airway dimensions and their role in the pathogenesis of OSA.

A systematic literature search showed a significant lack of knowledge and low confidence in screening OSA patients among dentists.[23,24] Previous publications have studied the upper airway dimensions in CBCT scans and the use of the STOP-Bang questionnaire as instruments to identify OSA.[8,10,17,18] However, some conflicting CBCT findings have been reported in upper airway dimension parameters. Furthermore, very few studies have discussed the correlation between CBCT scans and STOP-Bang scores as screening parameters.[25,26] Hence, this study aimed to investigate correlations between STOP-Bang scores and upper airway dimension parameters using CBCT scans to enable the early detection of OSA risk among dental patients, ensuring a timely referral to medical physicians.

Materials and Methods

This cross-sectional study was conducted at the Oral Health Centre of International Medical University. All eligible subjects during the study period were taken into consideration for participation. The participants were recruited from dental patients who had received a CBCT scan from 2014 to 2020. The inclusion criteria were subjects at least 18 years of age with CBCT scans displaying a sufficient field of view covering the nasopharynx, oropharynx, and appropriate tongue position. Subjects with edentulism, evident retrognathia and prognathia, or CBCT scans showing posterior positioning of the tongue were excluded from this study. Subjects without contact details were also excluded.

All 1269 CBCT scans taken were obtained and the subjects were contacted. Data collection was done through an online questionnaire (Google Forms) for the STOP-Bang risk assessment to reduce the risk of coronavirus disease 2019 transmission. Along with the STOP-Bang questionnaire, a study information sheet and consent form were sent to the subjects to obtain informed consent before the researchers accessed and analysed their CBCT images. Among these patients, 101 subjects responded (46 men, 55 women; mean age: 39.5 ± 16.29 years), resulting in a response rate of approximately 7.96% and achieving the targeted sample size of 100.

The targeted sample size was calculated based on Cochran's sample size formula:

$$n = Z^2 P (1 - P) / d^2$$

where, n = sample size, Z = Z statistic for a level of confidence (Z value is 1.96 for the level of confidence of 95%),

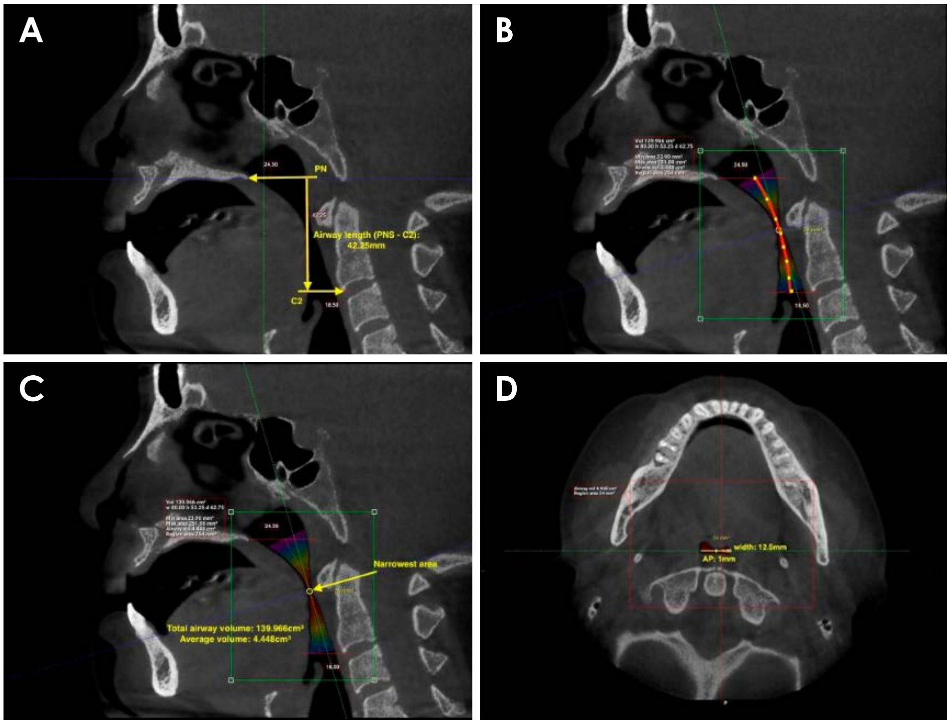

Fig. 1. A. A midsagittal image shows the total length of upper airway, denoted by the distance between posterior nasal spine (PNS) and the lowest border of the C2 vertebra. B and C. Midsagittal images show tracing of a curved line by joining dots placed in the middle of the airway to generate a 3-dimensional volumetric reconstruction pattern (rainbow-coloured region), which in turn allows an automatic generation of the total airway volume and average airway volume by the software. The arrow shows the narrowest area of the upper airway. D. Axial image of the narrowest area of the upper airway shows the smallest antero-posterior (AP) and narrowest width measurements.

P = expected prevalence or proportion (expressed as a decimal; i.e., if 7%, $P = 0.07$),[27,28] and d = precision (expressed as a decimal; i.e., if 5%, $d = 0.05$).

All scans were taken using a KaVo® 3D CBCT device (KaVo Dental GmbH, Biberach, Germany). The scans were previously performed as investigative procedures prior to dental treatment. The CBCT scans were interpreted using Planmeca Romexis® software (Planmeca Oy, Helsinki, Finland). The CBCT findings that were analysed included the total length of the upper airway, the total airway volume of the oropharyngeal region, the average airway volume of the oropharyngeal region, and the smallest width and antero-posterior (AP) measurements. The oropharynx region was isolated and analysed using manual segmentation of each axial slice. Using sagittal sections, the total length of the upper airway was gathered by measuring the length between the lowest border of the C2 vertebra and the posterior nasal spine (PNS) (Fig. 1A). Total airway volume was obtained through a 3-dimensional volumetric analysis of the upper respiratory tract obtained by tracing a curved line joining dots placed in the middle of the airway at each axial slice (Fig. 1B). The average airway volume was then automatically generated by the software by dividing the total airway volume by the number of axial slice segmentations (Fig. 1C). The narrowest area of the airway was determined by dragging a cursor along the curved line to check the average area at each section. The corresponding location was then viewed in an axial slice to obtain the upper airway's smallest width and AP measurements (Fig. 1D).

Risk assessment of the subjects was done using the STOP-Bang questionnaire, as shown in Table 1. According to the questionnaire responses, subjects were split into 2 categories: STOP-Bang score < 3 (low risk) and STOP-Bang score ≥ 3 (intermediate to high risk).[19] The CBCT findings of upper airway dimensions were then correlated with these 2 groups.

All the data were tabulated and analysed utilising SPSS version 22 (IBM Corp., Armonk, NY, USA). Descriptive statistics were determined for the upper airway dimension parameters as well as the quantitative data obtained through the STOP-Bang questionnaire (age, weight, height, and calculated body mass index [BMI]). The normality of all these variables were checked by the Kolmogorov-Smirnov test and Shapiro-Wilk test. Comparisons were made between the low-risk and intermediate/high-risk groups to identify variables with statistically significant between-group differences. Normally distributed continuous variables were tested via the parametric independent-sample t-test, whereas non-normally distributed variables were tested via the non-parametric Mann-Whitney test. Correlations between the total STOP-Bang score and upper airway dimension parameters were calculated using Spearman correlation coefficients. In all tests, a P value < 0.05 was considered to indicate statistical significance.

Table 1. STOP-Bang questionnaire

STOP	Do you **S**NORE loudly (louder than talking or loud enough to be heard through closed doors)?	YES	NO
	Do you often feel **T**IRED, fatigued, or sleepy during daytime?	YES	NO
	Has anyone **O**BSERVED you stop breathing during your sleep?	YES	NO
	Do you have or are you being treated for high blood **P**RESSURE?	YES	NO
BANG	**B**MI more than 35 kg/m^2?	YES	NO
	Weight = Height =		
	BMI = weight/height (m^2) =		
	AGE over 50 years old?	YES	NO
	NECK circumference > 16 inches (40 cm)?	YES	NO
	GENDER: Male?	YES	NO
TOTAL SCORE			

Table 2. Distribution of participants by sex and neck circumference

Factor	Low-risk subjects (n = 79)		Intermediate/high-risk subjects (n = 22)	
	Frequency	Percent (%)	Frequency	Percent (%)
Sex				
Male	27	34.2	19	86.4
Female	52	65.8	3	13.6
Neck circumference				
<40 cm	79	100	14	63.6
≥40 cm	0	0	8	36.4

Table 3. Comparison between low-risk and intermediate/high-risk subjects

	Low-risk subjects (n = 79)	Intermediate/ high-risk subjects (n = 22)
Demographic factors		
Age (years)	36.6 ± 15.2	50.1 ± 15.9*
Height (cm)	164.86 ± 9.42	169.96 ± 7.62*
Weight (kg)	61.07 ± 13.71	79.82 ± 14.33*
BMI (kg/m^2)	22.26 ± 4.54	27.76 ± 5.42*
Upper airway dimension parameters		
Length (mm)	41.94 ± 6.45	45.10 ± 4.79*
Total volume (cm^3)	130.75 ± 18.48	134.98 ± 15.67
Average volume (cm^3)	11.75 ± 5.26	8.77 ± 4.37*
Antero-posterior (mm)	6.80 ± 3.36	5.14 ± 2.06*
Width (mm)	22.71 ± 5.99	18.02 ± 7.24*

BMI: body mass index, *: $P < 0.05$

Results

In total, 101 respondents (11 Malays, 76 Chinese, 9 Indians, 2 Caucasians, 1 Sarawak aboriginal, 1 Eurasian, and 1 Burmese) participated in this study. Among them, 79 (8 Malays, 62 Chinese, 6 Indians, 1 Burmese, 1 Sarawak aboriginal, 1 Eurasian) were categorised as low-risk for OSA, with a score of <3 in the STOP-Bang risk assessment. The remaining 22 respondents (3 Malays, 13 Chinese, 3 Indians, 2 Eurasians) were subsequently placed into the intermediate/high-risk group, with a score of ≥3 in the STOP-Bang risk assessment.

Table 2 shows the frequency distributions of qualitative data, including sex and neck circumference >40 cm, for both groups. The intermediate/high-risk group had a higher percentage of men (86.4%), whereas the low-risk group had a higher percentage of women (65.8%), supporting the hypothesis that men are more susceptible to OSA. All the low-risk subjects had a neck circumference <40 cm, whereas 8 out of 22 (36.4%) of the intermediate/high-risk group showed a neck circumference ≥40 cm.

As shown in Table 3, the low-risk subjects were significantly younger (mean age: 36.6 ± 15.2 years) than the intermediate/high-risk subjects (mean: 50.1 ± 15.9 years). Subjects with a higher risk of OSA were heavier (79.82 ± 14.33 kg) and had a higher BMI (27.76 ± 5.42 kg/m^2).

The oropharyngeal upper airway of each subject was visualized in sagittal and axial views, as demonstrated in Figure 2 (low-risk subjects) and Figure 3 (intermediate/high-risk subjects). As depicted in these figures, the low-risk subject with a STOP-Bang score of 1 showed an evidently more patent airway than the high-risk subject with a STOP-Bang score of 5. The higher risk subject had a greater length, smaller total volume, smaller average volume, and smaller width and AP dimensions of the narrowest airway section.

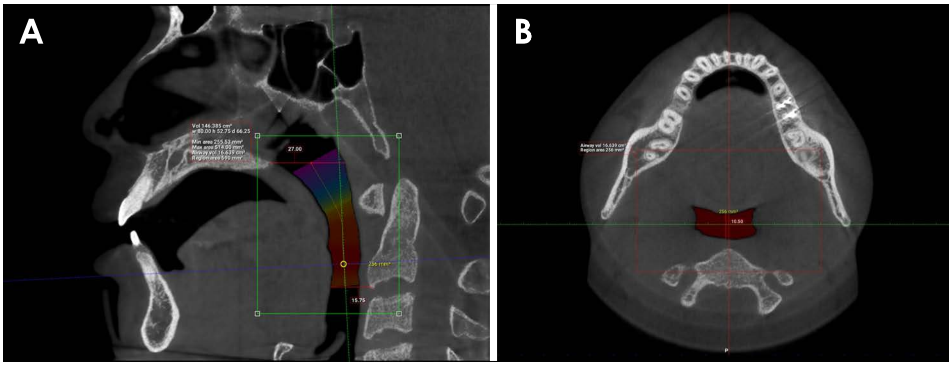

Fig. 2. Midsagittal (A) and the narrowest axial (B) images of the upper airway of a low-risk subject (STOP-Bang score = 1) show a more patent airway (total volume: 146.385 cm^3, average volume: 16.639 cm^3, length: 45.51 mm, antero-posterior measurement: 10.5 mm, width: 25 mm).

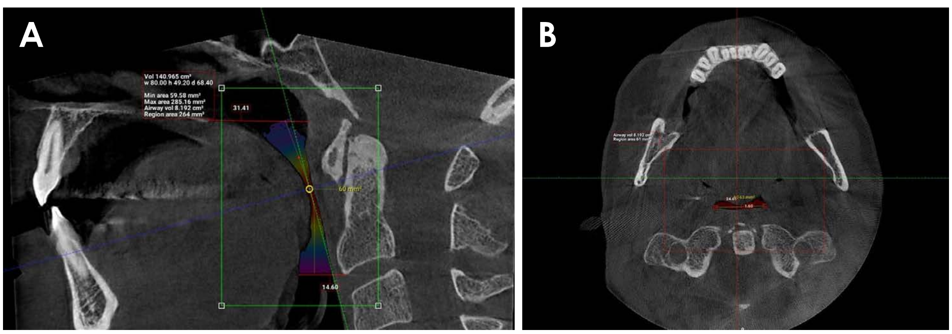

Fig. 3. Midsagittal view (A) and the narrowest axial (B) images of the upper airway of a high-risk subject (STOP-Bang score = 5) show a more constricted airway (total volume: 140.965 cm^3, average volume: 8.192 cm^3, length: 48.01 mm, antero-posterior measurement: 1.6 mm, width: 24.61 mm).

The parametric independent-sample *t*-test revealed significant differences in length and width between the 2 groups. The intermediate/high-risk group had slightly longer (45.10 ± 4.79 mm) and narrower (18.02 ± 7.24 mm) airways.

As shown by the nonparametric Mann-Whitney test, there were significant differences in the average volume and AP dimension between the two different OSA risk groups. The intermediate/high-risk group demonstrated a lower average volume (8.77 ± 4.37 cm^3) and a smaller AP dimension of the narrowest airway axial slice (5.14 ± 2.06 mm). The relevant data are displayed in Table 3.

To investigate the correlations between the STOP-Bang score and the upper airway dimensions, Spearman correlation analysis was carried out. The results revealed a positive correlation between the total length of the upper airway (PNS-C2 distance) with the total STOP-Bang score (r_s = 0.278). On the contrary, a negative correlation (r_s = −0.305) was found between the width of the narrowest upper airway axial slice and the total STOP-Bang score. A negative correlation (r_s = −0.203) was also found between the average volume and the total STOP-Bang score. This indicates that subjects with a higher risk of OSA often had a longer airway with a smaller average airway volume and smaller width at the narrowest cross-section of the upper airway.

A simple linear regression graph, as shown in Figure 4, was plotted to demonstrate the relationship between the upper airway dimension parameters and the STOP-Bang score. The dotted line and double solid line demonstrate

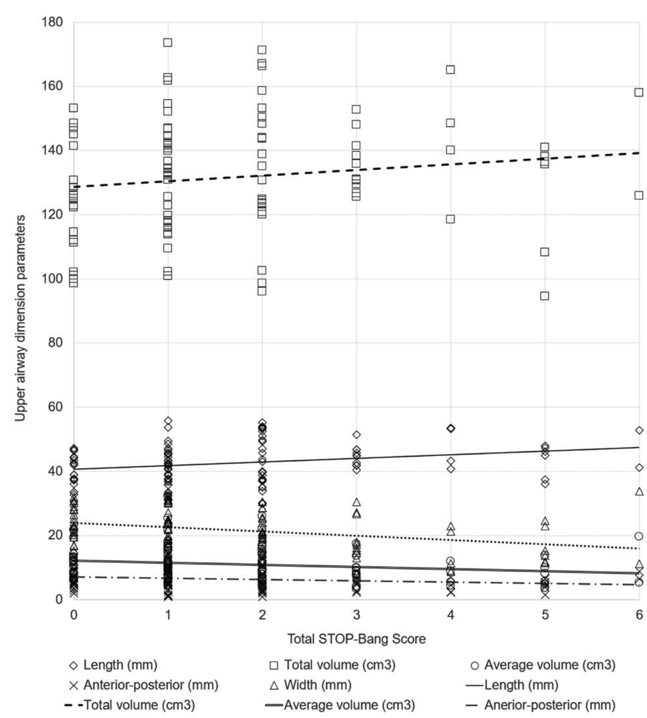

Fig. 4. Linear regression graph shows the trends of each upper airway dimension parameter according to the total STOP-Bang scores.

that the width and average volume of the narrowest upper airway area decreased as the total STOP-Bang score increased. In contrast, the solid line indicating the total length of the upper airway (PNS-C2 distance) displayed an upward trend with an increase of the total STOP-Bang score.

Discussion

A systematic review regarding the STOP-Bang questionnaire conducted by Nagappa et al.,[18] which included 9,206 patients, showed that a cut-off score of ≥ 3 consistently demonstrated high sensitivity (around 94%) in detecting OSA in various populations. Hence, the same cut-off score of ≥ 3 was used in this study to split the subjects into groups that had a low risk (n = 79) or an intermediate to high risk (n = 22) of developing OSA before comparing different variables including age, sex, BMI, neck circumference and upper airway parameters between these 2 groups.

The subjects with an intermediate to high risk of developing OSA were significantly older (mean age: 50.09 ± 15.93 years) than their low-risk counterparts. Similarly, 2 prior studies also reported that the frequency of OSA rises with age.[29,30]

BMI was also shown to be significantly different between the lower risk group (22.26 ± 4.54 kg/m^2) and the intermediate/high-risk group (27.76 ± 5.42 kg/m^2). Furthermore, all low-risk subjects (100%) in the present study had a neck circumference < 40 cm, whereas 36.4% of the intermediate/high-risk group showed a neck circumference ≥ 40 cm. These findings are consistent with the hypothesis that tissue pressure on the pharyngeal wall increases with fat deposition within the parapharyngeal structures, predisposing it towards a higher tendency of upper airway collapse. This hypothesis was further reinforced by other imaging studies demonstrating increased adipose tissue deposition in the tongue, lateral pharyngeal fat pads, and soft palate in obese patients with OSA.[22]

Another significant finding in the present study was the higher proportion of men in the intermediate/high-risk group (86.4%) and the lower proportion of women in the low-risk group (65.8%). A higher percentage of OSA in men has been consistently reported, and Kim et al.[31] reported differences in symptomatic presentation according to sex.

Regarding upper airway dimensions, significant differences were reported for length, average volume, as well as both the AP dimension and width of the narrowest axial slice between the 2 groups. The only exception was that the total volume of the upper airway showed a non-significant difference ($P > 0.05$) between the 2 groups. The finding of a non-significant difference in the total upper airway volume between groups was consistent with the results of a study by Kim and colleagues.[32]

To further determine the correlation between the STOP-Bang score and upper airway parameters, Spearman correlation analysis was conducted. A positive correlation was found between the total length of the upper airway (PNS-C2 distance) and the total STOP-Bang score, ($r_s = 0.278$). Furthermore, a negative correlation ($r_s = -0.305$) between the width of the narrowest upper airway axial slice and the total STOP-Bang score was observed. A negative correlation ($r_s = -0.203$) was also found between the average volume and the total STOP-Bang score. In other words, subjects with a higher risk of OSA and a higher STOP-Bang score often had a longer airway with a smaller average volume and smaller width at the narrowest portion of the upper airway.

Similar findings in terms of a significant negative correlation between airway length and OSA risk were reported by Kim et al.,[32] Sursala et al.,[33] and Buchanan et al.[8] In addition, Buchanan et al. also demonstrated smaller airway width and average volume in OSA subjects. Another study that supports the findings of the present study was conducted by Enciso and colleagues, who found that the narrowest width of the upper airway was significantly smaller in OSA patients.[10] Schwab and colleagues similarly reported a predominant pattern of lateral airway narrowing in apnoeic patients despite insignificant differences in the AP measurements.[34]

More importantly, the findings of the present study are consistent with those of Momany et al.[35] and Abramson et al.,[36] who reported greater airway length and a smaller width of the narrowest upper airway cross-section in OSA patients. Mamony et al. specifically presented cut-offs for the length of the upper airway (> 50.1 mm) and width of the narrowest upper airway section (< 37.4 mm^2) that predicted a higher risk of OSA. However, unlike the present study, Abramson et al. found a significant negative association between the AP airway dimension and OSA risk. Furthermore, Buchanan et al. also reported a contrasting finding in their study, wherein a smaller total volume of the upper airway was observed in OSA patients.[8]

The role of a longer airway, lower average airway volume, and narrower minimum cross-section of the upper respiratory tract in the etiopathogenesis of OSA can be explained using Poiseuille's law for resistance $\left(R = \frac{8\eta l}{\pi r^4}\right)$. According to this equation, the resistance towards airflow (R) is proportional to the length of the airway (l) as well as inversely proportional to the fourth power of the radius

(r), where viscosity (η) remains constant. Thus, in patients with a greater length and smaller width of the narrowest upper airway cross-section, there is a significantly higher resistance towards air flow, thereby decreasing the air flow rate.[22] With a decreased air flow rate, the airway will then have a higher tendency of collapsing due to an imbalance of forces.[37] The differences in pressure caused by collapsing and dilating forces determine the upper airway patency. Since pressure is defined as the force exerted per cross-sectional area, a longer and narrower airway is thus more liable to obstruction due to the greater extra-luminal collapsing force and pressure.[22]

The strengths of this study include the fact that it involved an analysis of CBCT scans that were already taken for clinical purposes, which minimised the radiation dose for patients and increased the cost-effectiveness of the study. Furthermore, the subjects had a wide age range (18-75 years; mean age: 39.5 ± 16.3 years) as well as a nearly even sex distribution (46 men and 55 women), enabling a fairly close representation of the population, thus allowing extrapolation of the data to the broader Malaysian population. The multiracial composition of the sample, despite the unequal distribution (10.89% Malays, 78.22% Chinese, 8.91% Indians, 4.95% others), improves the generalizability of the data, as opposed to focusing on just a single race.

However, there are also several limitations of this study. First, it used previous CBCT images that were captured in an upright position, as opposed to the supine position, which would simulate usual sleeping positions. Previous studies have demonstrated evident differences in measurements of the upper respiratory tract volume in upright and the supine positions, with a decrease of 32.6% observed in the supine position. Moreover, the most significant decrease in size was seen in the smallest axial slice of the upper airway, with an average of 75.9%.[38]

Lastly, sampling bias and participant bias might have been present in this study. Despite an attempt to select all patients according to patient registration numbers from 2014 to 2020, a response rate of only roughly 7.96% was achieved. The participants who chose to participate might have had a disproportionate likelihood of suspecting that they suffered from OSA, thus motivating them to participate and resulting in a possible sampling bias. As the STOP-Bang data collection was conducted through an online questionnaire, participant bias might have taken place as subjects might have responded in a way that they believed to correspond with what the researchers were looking for. It was also difficult to verify the accuracy of the information given by subjects through this method.

With the increased usage of CBCT in dental practice, dentists should pay close attention to the upper airway dimensions captured to identify any incidental findings that may indicate an elevated risk of OSA. Any patients suspected to have OSA should then be assessed using the 8 simple targeted questions from the STOP-Bang questionnaire to obtain a total score. The findings obtained from CBCT scans and the STOP-Bang score can be correlated to evaluate patients' risk of OSA. Patients suspected to be at high risk for OSA ought to be promptly referred to physicians for further definitive management.

In conclusion, this study found that subjects with higher STOP-Bang scores tended to have upper airways that were longer, narrower, and of smaller average volume. CBCT scans taken for dental patients as part of their investigative procedures can be cross-referenced with STOP-Bang scores to screen for patients at risk of developing OSA. Further studies with larger sample sizes are recommended. More systematic reviews and meta-analyses are also warranted.

Conflicts of Interest: None

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