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Three-dimensional linear and volumetric analysis of maxillary sinus pneumatization

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ABSTRACT

Considering the anatomical variability related to the maxillary sinus, its intimate relation to the maxillary posterior teeth and because of all the implications that pneumatization may possess, three-dimensional assessment of maxillary sinus pneumatization is of most usefulness. The aim of this study is to analyze the maxillary sinus dimensions both linearly and volumetrically using cone beam computed tomography (CBCT) to assess the maxillary sinus pneumatization. Retrospective analysis of 30 maxillary sinuses belonging to 15 patients' CBCT scans was performed. Linear and volumetric measurements were conducted and statistically analyzed. The maximum craniocaudal extension of the maxillary sinus was located around the 2nd molar in 93% of the sinuses, while the maximum mediolateral and antroposterior extensions of the maxillary sinus were located at the level of root of zygomatic complex in 90% of sinuses. There was a high correlation between the linear measurements of the right and left sides, where the antroposterior extension of the sinus at level of the nasal floor had the largest correlation (0.89). There was also a high correlation between the Simplant and geometric derived maxillary sinus volumes for both right and left sides (0.98 and 0.96, respectively). The relations of the sinus floor can be accurately assessed on the different orthogonal images obtained through 3D CBCT scan. The geometric method offered a much cheaper, easier, and less sophisticated substitute; therefore, with the availability of software, 3D volumetric measurements are more facilitated.
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Introduction

Maxillary sinus pneumatization can pose a surgical hazard in terms of oro-antral communications following extraction [1,2] and endodontic surgery of the antral related teeth [3]. It also increases the risk of introducing foreign bodies, root tips, or teeth displacement into the sinus cavity [4], and it is well known to influence orthodontic teeth movement [5–7]. Oro-antral communications facilitate microbial contamination of the maxillary sinus. If the communication remains open or if the infection persists, chronic inflammation of the sinus' membrane may result with subsequent permanent epithelization of the oro-antral fistula – a situation that further increases the risk of sinusitis [2].

Lastly and needless to say that implant-supported rehabilitation of posterior maxilla is jeopardized by the natural tendency of the maxillary sinus to pneumatize bone during life and the inherent bone remodeling, which pursue teeth loss

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causing rapid alveolar bone resorption. Implant insertion within inadequate bone quantity carry risk of oro-antral communication and in such circumstance, maxillary sinus floor elevation is predictable and the possibility of using graft material is not even far. Both procedures require extra preoperative planning [8–12]. The sound knowledge and preoperative vision of this region will assist the surgeon to be more confident and be familiar with the common anatomic variants and to avoid such serious complications.

Periapical, panoramic, and conventional CT [13] have been recommended for the preoperative planning. In many clinical situations, the use of three-dimensional imaging proved to be beneficial as compared to two-dimensional imaging and overcomes its limitations [14,15]. CT scan was developed to overcome the lack of cross-sectional information, superimposition, distortion, and magnification noted in the conventional radiography [6,16–18].

Exploring the normal radiographic anatomy of the maxillofacial region has reached areas that were hidden in the past. This is true concerning the maxillary sinus pneumatization especially with the increased reliability of 3D imaging. Three-dimensional CT technologies have greatly improved the ability to explore the interior of the cranium and to estimate the volumes of different anatomical compartments such as the maxillary sinus and the nasal cavity. It also facilitated the correlation between these anatomical compartments and the different ethnic groups relative to climate variations. However, the large dose of ionizing radiation delivered by medical CT is crucial and debatable [19–21].

Outstandingly, the CBCT technology has achieved considerable reduction of absorbed radiation doses compared to medical CT imaging and a bit similar to dental panoramic radiography [22–24]. Field of view limitations have further reduced the effective dose. Standard dental protocol scans using traditional CT delivers 1.5–12.3 times greater radiation than comparable medium field of view dental CBCT scans [24]. Till that moment, the image quality of CBCT was adjudged to be equivalent to that of traditional CT for visualizing the maxillofacial structures. Moreover, beam-hardening artifacts due to dental-filling materials and implants are far weaker at CBCT than CT [25–28].

Considering the anatomical variability related to the maxillary sinus, its intimate relation to the maxillary posterior teeth, and because of all the implications that pneumatization may possess, three-dimensional assessment of maxillary sinus pneumatization is of most usefulness. This is especially the case whenever surgical endodontic apicectomy, periodontal flaps, surgical extraction, implant installation, orthognathic surgeries, or surgical intervention for space occupying lesions involving the maxillary sinus and/or the maxilla are intended.

The literature on this direction using CBCT is rather scarce [6,26,29]. Therefore, the aim of this study was to analyze the maxillary sinus dimensions both linearly and volumetrically to assess the maxillary sinus pneumatization.

Patients and methods

The present study was performed as a retrospective analysis of data stored in a private radiology center. Out of respect for doctor patient confidentiality, all personal information concerning the patients as well as the diagnostic cause of the CBCT scan was hidden. The inclusion criteria of patients to the study were based solely on the radiologists' interpretation about lack of mucosal thickening in either maxillary sinuses as well as any bone deformities. Fully edentulous patients were excluded. Fifteen patients were selected and informed consent was taken from them. Both sinuses in 15 patients' scans were measured giving rise to data from 30 sinuses.

Images were acquired using the i-CAT Imaging system (Next Generation, Imaging Sciences International, Hatfield, USA). The patients were exposed in the sitting position and immobilized using a head band to adjust the head against the head rest and chin cup. The mid-sagittal plane was aligned to be perpendicular to the horizontal plane using vertical and horizontal alignment beams as recommended by the manufacturer. The i-CAT is equipped with an amorphous Silicon Flat Panel, and a single 360 degrees scan collects the projection data for reconstruction. The X-ray field size applied was 16 cm diameter × 13 cm height, and scanning time was 8.9 s (fast enough to avoid patient movement, image blurring, and haziness). Operating parameters were 120 kVp and 5 mA with slice thickness of 0.3 mm (the standard resolution for scanning at i-CAT machine). The i-CAT's Vision software (Imaging Sciences International) was used which allows the recording of linear measurements of images. The measurements were performed by observer (N A.-W.), who has a 15 years experience in oral and maxillofacial radiology. This study was approved by the Research Ethics Committee, Faculty of Oral and Dental Medicine, Cairo University.

Sinus linear measurements

The linear measurements were performed according to a protocol that was tested elsewhere for inter- and intraobserver agreement and showed statistically non-significant differences between the observers [30]. Since there were no radiopaque markers used in this study, the selection of the cuts for measuring sinus dimensions was based on the presence of certain anatomical landmarks. According to the anatomical fact that the maxillary sinus is pyramidal in shape with an almost square base oriented medially [31], the measurements of the sinus dimensions were conducted as follows:

1. Linear measurements of the maxillary sinus length (craniocaudal extension; CC): On the i-CAT Vision software, MPR was chosen for interfacing; adjusting the orientation axis for the axial cut parallel to the occlusal plane at the alveolar crest level; adjusting the orientation axis of the sagittal cut to be midway between buccal and palatal cortices; adjusting the coronal cut at area of intended measurement by rotation of the axial image till the orientation axis for the coronal cut becomes perpendicular on buccal cortex. This was repeated at interdental areas between upper first and second premolars, upper second premolar and upper first molar, upper first and second molars, upper second and third molars; giving rise to 4 craniocaudal measurements: CC 1st and 2nd premolars, CC 2nd premolar and 1st molar, CC 1st and 2nd molars and CC 2nd and 3rd molars, respectively, for each side (Fig. 1). The coronal cut oriented exactly interdental was used (its axis of orientation in the axial cut was positioned interdentally). The measurements were taken from the lowest point of the cortical boundary of orbital floor to the lowest border of the cortical boundary of the sinus floor. To standardize the

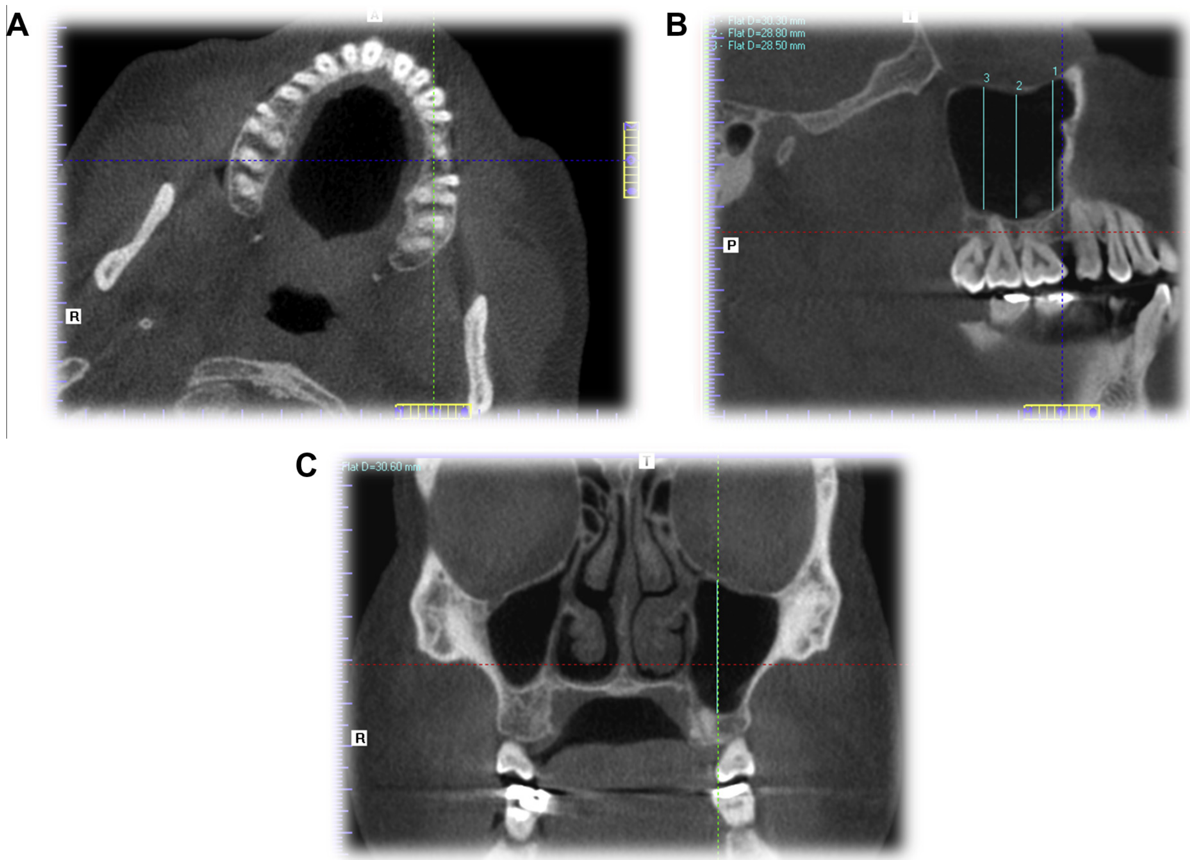

Fig. 1 (A) Adjustment of coronal cut at area of intended measurement by rotation of the axial image till the orientation axis for the coronal cut (blue line) becomes perpendicular on buccal cortex. This adjustment was repeated at interdental areas between upper first and second premolars, upper second premolar and upper first molar, upper first and second molars, upper second and third molars; giving rise to 4 craniocaudal measurements CC 45, CC56, CC 67, and CC78 respectively for each side. (B) The four areas intended for craniocaudal measurements represented on the sagittal cut. (C) Coronal cut revealing the actual craniocaudal measurement conducted along the orientation axis for the sagittal cut (bluish-green line).

measurements, they were conducted along the orientation axis apparent on the cut to take the advantage of being automatically adjusted by the software used.

2. Linear measurements of the maxillary sinus width (antroposterior dimension; AP) and height (mediolateral dimension; ML) were performed on two levels; along nasal floor and along root of zygoma giving rise to 4 measurements: AP NS, AP ZG, ML NS, and ML ZG, respectively, on each side. To standardize the axial cut used for measurements, its orientation axis in the coronal cut was adjusted to be exactly passing bilaterally along the inferior cortical boundary of the nasal cavity and root of zygoma, respectively. The measurements were repeated till the maximum antroposterior and mediolateral dimensions were obtained (Figs. 2 and 3).

The selected sites for linear measurements were 16 in number giving rise to a total of 240 readings. All measurements were taken in mms.

Sinus volume determination

Ten sinuses for five patients (out of the original fifteen) were then selected for further volumetric analysis of the maxillary sinus. Selection criteria were based on inclusion of all sinus boundaries within the scan. Right and left volumetric measurements were taken for the five patients.

1- Volume determination via segmentation technique using Simplant software (Simplant, Materialise Dental NV, Leuven, Belgium) [31].
2- Volume determination via geometric calculation method according to the geometrical equation: Volume of Pyramid = Base Surface Area $\times$ 1/3 Height.

Volume of maxillary sinus (Pyramid) = antroposterior (width) $\times$ craniocaudal(length) $\times$ mediolateral(height)/3.

In order to obtain the width, length, and height of the sinus, the coronal and axial cuts were sequentially reviewed to get maximum height of the sinus [mediolateral dimension] and the sagittal cuts were sequentially reviewed to get the maximum sinus base width [antroposterior dimension] and length [craniocaudal dimension] (Fig. 4).

The amount of the maxillary sinus pneumatization was calculated relative to the highest level of the sinus floor expected at the distal side of the 1st premolar (where the sinus floor is supposed to start) by subtracting this value from the other measured craniocaudal values; e.g., sinus pneumatization

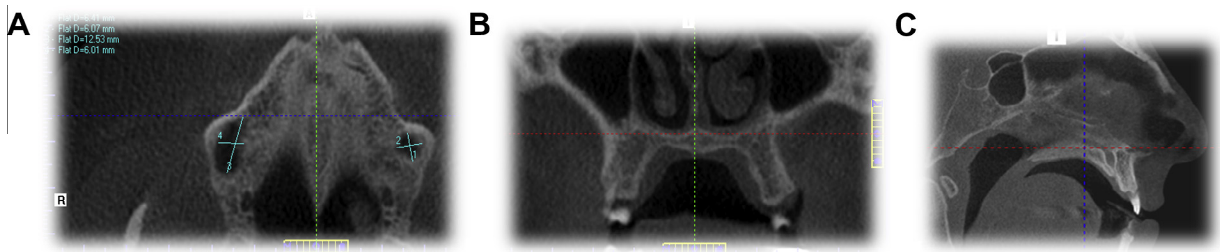

Fig. 2 (A) Antroposterior (1 and 3) and mediolateral (2 and 4) measurements conducted along the nasal floor (AP NS, ML NS) on axial CBCT scan. Coronal (B) and Sagittal (C) cuts showing the axial orientation axis (red horizontal line) denoting the level of axial scan along the nasal floor.

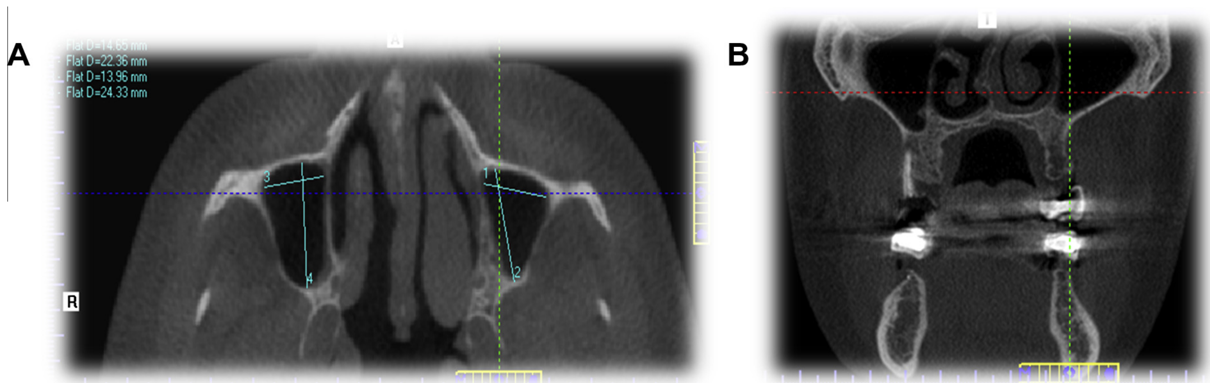

Fig. 3 (A) Antroposterior (2 and 4) and mediolateral (1 and 3) measurements conducted along the root of zygoma level (AP ZG, ML ZG) on axial CBCT scan. (B) Coronal CBCT scan showing the axial orientation axis (red horizontal line) denoting the level of axial scan along the root of zygoma.

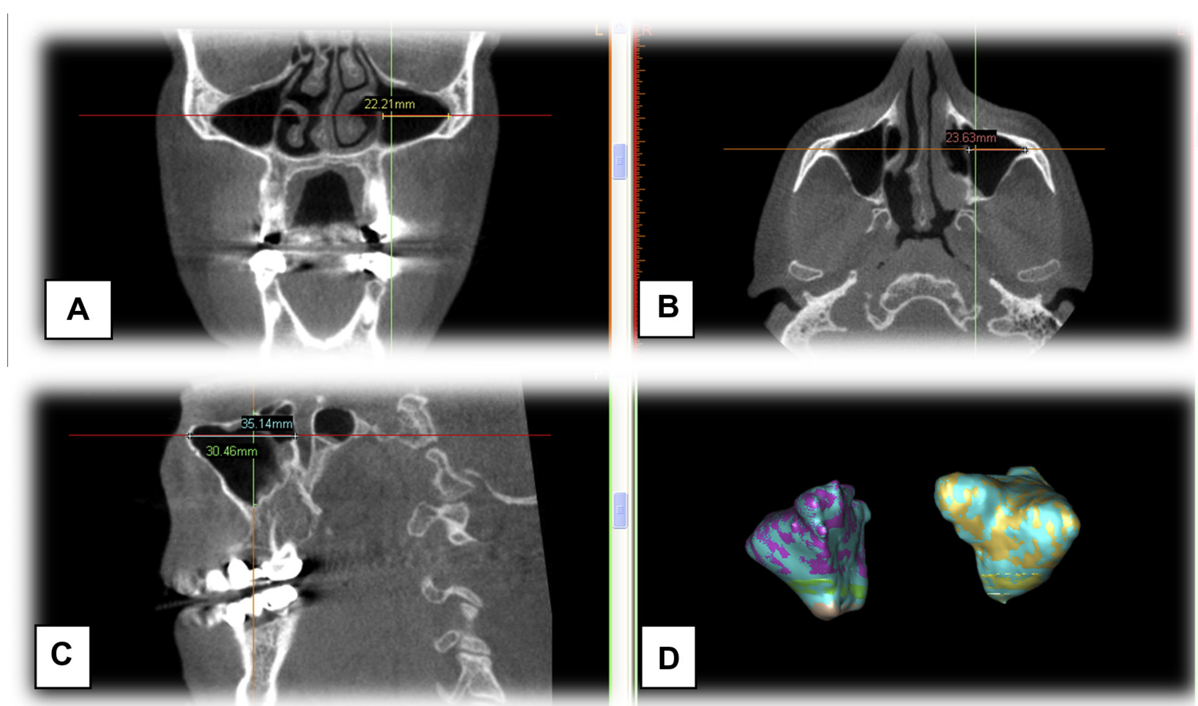

Fig. 4 Mediolateral dimension of the maxillary sinus conducted on coronal (A) and axial (B) CBCT scans to calculate the height of the pyramidal sinus. Antroposterior and craniocaudal dimensions conducted on sagittal (C) CBCT scans to calculate the surface area of the pyramid's base (width and length). (D) 3D volumetric measurement of the maxillary sinus using the Simplant software.

between the 2nd and 3rd molars = craniocaudal dimension between the 2nd and 3rd molars – craniocaudal dimension between the 1st and 2nd premolars. In cases where the sinus was absent at the area between 1st and 2nd premolars, the craniocaudal dimension between the 2nd premolar and 1st molar was used in the subtraction equation. Descriptive statistics were used for all the measurements. The average, standard deviation, coefficient of variation, and 95% confidence interval values for the craniocaudal, mediolateral, and antroposterior dimensions were calculated for the right and left sides of each patient separately. The Pearson's correlation coefficient was used to evaluate the correlation between right and left 2D linear measurements for sinus symmetry as well as the correlation between 3D Simplant and geometrically derived volumetric measurements. Student's paired t-test was also performed for the linear measurements (sample size = 15). Statistical significance was set at $p \leqslant 0.05$.

Results

The maximum craniocaudal extension of the maxillary sinus was located around the 2nd molar in 28 sinuses out of 30 (93%). Maximum craniocaudal extension of the maxillary sinus was located distal to the 2nd molar in 15 sinuses out of 30 (50%) followed by the mesial side of the 2nd molar (11 sinuses out of 30 = 36%). In only two sinuses, the craniocaudal extension of the maxillary sinus was equal on both sides around the 2nd molar. The maximum craniocaudal extension of the maxillary sinus was seen around the 1st molar in one sinus only and it was equal on both the distal and the mesial sides. In another sinus, the maximum craniocaudal extension of the maxillary sinus was seen between the 2nd premolar and 1st molar. Almost in all cases, the maxillary sinus showed least craniocaudal extension around the 1st premolar. 4 sinuses (bilateral in 2 patients) began more distally at the area of the 2nd premolar and one sinus did not reach beyond the level of 2nd molar. The largest average for craniocaudal dimensions was mesial to the 2nd molar (35.54 ± 3.96 mm) (Table 1).

The maximum mediolateral extension of the maxillary sinus was located at the level of root of zygomatic complex in 90% of sinuses (27 sinuses out of 30). The maxillary sinus was located at a higher level than the nasal floor in 3 sinuses (10% of sinuses), 2 of these sinuses were in the same patient. The maximum antroposterior extension of the maxillary sinus was seen at the level of the root of zygomatic complex in 90% of sinus (27 sinuses out of 30). In 3 sinuses, the maximum antroposterior extension was seen at the level of the nasal floor, 2 of them were in the same patient. The sinus was bilaterally absent at the level of nasal floor in the same case that did not pneumatize distal to the 2nd molar and was absent in the right side of another case. The largest average for mediolateral and antroposterior dimensions was at the zygomatic complex level with amounts of 20.43 ± 2.62 mm and 31.54 ± 3.2 mm, respectively (Table 2).

The amount of sinus pneumatization was calculated relative to the craniocaudal extension of the sinus between the 1st and 2nd premolars. In the two cases where the sinus anatomically started at the 2nd premolar level, the amount of pneumatization was calculated relative to the craniocaudal extension at the 2nd premolar. Thus, in these two cases, no value was recorded for sinus pneumatization between 2nd premolar and 1st molar. In a single case, the extension of the sinus did not reach the 3rd molar so no value was recorded for this site. Negative pneumatization values denote higher si-

Table 1 Craniocaudal (CC) extensions of the maxillary sinus and their averages at the different anatomic locations [Lt (left), RT (right)]. CC extension is measured interdental/proximal between 1st and 2nd premolars, 2nd premolar and 1st molar, 1st and 2nd molars and between 2nd and 3rd molars. All measurements are in mm.

Case No	Lt CC 1st and 2nd premolars	Lt CC 2nd premolar and1st molar	Lt CC 1st and 2nd molars	Lt CC 2nd and 3rd molars	Rt CC 1st and 2nd premolars	Rt CC 2nd premolar and1st molar	Rt CC 1st and 2nd molars	Rt CC 2nd and 3rd molars
1	17.1	23.9	28	30.6	8.9	21.3	30.9	17.6
2	30.7	34.8	34.2	36.8	29.9	32.5	33.6	36.3
3	25.5	26.8	40	34.2	23.7	29.6	37.7	32.7
4	9.3	16.5	27.9	32.1	11.5	16.3	28.6	28.5
5	13.3	19	27.7	26.2	20	29.9	35.4	31.2
6	Absent	21.3	32.8	34.9	Absent	22.9	29.2	33.6
7	22.4	36.6	34.6	39.4	24.1	37.6	38.1	39
8	11.5	16.9	30.1	12.1	10	17.4	21.6	Absent
9	21.3	37.6	48	47	16.5	23.1	45	45
10	26.1	33.8	33.7	24	22.2	32.4	34.9	25.2
11	Absent	17	22.2	27	Absent	19.4	25.9	29.7
12	32.1	37.7	42.4	41.7	30.3	31.8	36.9	39.5
13	38.9	44	42.1	36	27.9	34.2	39	37.8
14	15.7	40.2	41.1	49.5	17.5	37.4	36.3	39.1
15	24.6	40.5	48.4	53.7	25.3	42.6	47.6	50.1
Average	22.19	29.77	35.54	35.01	20.60	28.56	34.71	34.66
SD	8.70	9.90	7.83	10.64	7.29	8.04	6.82	8.22
CV%	39.24	33.28	22.04	30.41	35.42	28.16	19.65	23.73
95% CI	22.19 ± 4.40	29.77 ± 5.01	35.54 ± 3.96	35.01 ± 5.38	20.6 ± 3.69	28.56 ± 4.07	34.71 ± 3.45	34.66 ± 4.16

SD = standard deviation, CV% = coefficient of variation, 95%CI = 95%confidence interval.

Table 2 Mediolateral and antroposterior extensions of the maxillary sinus and their averages at the level of nasal floor and root of zygoma [RT (right), Lt (left), ML (mediolateral), AP (antroposterior), NS (level of nasal floor), ZG (level of root of zygoma)]. All measurements are in mm.

Case No.	Lt ML NS	Lt ML ZG	Lt AP NS	Lt AP ZG	Rt ML NS	Rt ML ZG	Rt AP NS	Rt AP ZG
1	11.1	21.5	11	25.8	9	19.2	22	28.8
2	21.3	25.5	38.9	39.4	17.7	22.3	35.4	38
3	18.6	21.9	36.9	40.9	17.4	18.9	36.9	40.8
4	9.6	16.8	13.2	27	Absent	13.5	Absent	27.3
5	8.1	15.8	7.8	24.9	5.4	16.2	9.3	28.8
6	14.7	18.6	31.2	32.6	14.4	22.4	33.1	38.6
7	16.8	25.8	32.6	32.9	22.5	24.6	34.8	35.1
8	Absent	12.3	Absent	22.9	Absent	10.5	Absent	17.2
9	14.4	18.6	25.5	31.2	16.9	19.8	24.4	29.8
10	14.9	19.2	12.8	32	16.2	23.1	22	31.5
11	6.3	16.5	10.5	24.9	10	14.7	20.5	29.8
12	13.8	34.3	33.7	18.1	14.1	38	31	23.4
13	17.1	20.1	21.6	29.2	12	18	15.7	31.6
14	15.2	20.1	35	34.5	18.1	17.7	31.3	33.5
15	14.7	19.5	40.3	38.6	18.1	27.1	37.8	39
Average	14.04	20.43	25.07	30.32	14.75	20.40	27.24	31.54
SD	4.08	5.18	11.90	6.50	4.61	6.54	8.93	6.32
CV%	29.10	25.35	47.48	21.43	31.31	32.09	32.77	20.05
95% CI	14.04 ± 2.06	20.43 ± 2.62	25.07 ± 6.02	30.32 ± 3.28	14.75 ± 2.33	20.4 ± 3.31	27.24 ± 4.51	31.54 ± 3.20

SD = standard deviation, CV% = coefficient of variation, 95%CI = 95%confidence interval.

Table 3 Amount of maxillary sinus pneumatization and their averages at the different anatomic locations relative to sinus craniocaudal extension between 1st and 2nd premolars (or between 2nd premolar and 1st molar). All measurements are in mm. (Lt = left, Rt = right).

Case No.	(Lt) between 2nd premolar and 1st molar	(Lt) between 1st and 2nd molars	(Lt) between 2nd and 3rd molars	(Rt) between 2nd premolar and 1st molar	(Rt) between 1st and 2nd molars	(Rt) between 2nd and 3rd molars
1	6.8	10.9	13.5	12.4	22	8.7
2	4.1	3.5	6.1	2.6	3.7	6.4
3	1.3	14.5	8.7	5.9	14	9
4	7.2	18.6	22.8	4.8	17.1	17
5	5.7	14.4	12.9	9.9	15.4	11.2
6	Absent between premolars	11.5	13.6	Absent between premolars	6.3	10.7
7	14.2	12.2	17	13.5	14	14.9
8	5.4	18.6	0.6	7.4	11.6	
9	16.3	26.7	25.7	6.6	28.5	28.5
10	7.7	7.6	−2.1	10.2	12.7	3
11	Absent between premolars	5.2	10	Absent between premolars	6.5	10.3
12	5.6	10.3	9.6	1.5	6.6	9.2
13	5.1	3.2	−2.9	6.3	11.1	9.9
14	24.5	25.4	33.8	19.9	18.8	21.6
15	15.9	23.8	29.1	17.3	22.3	24.8
Average	9.21	13.76	13.22	9.10	14.04	13.22
STDEV	6.52	7.59	10.97	5.49	6.91	7.28
CV%	70.83	55.18	82.97	60.33	49.27	55.08
95% CI	9.21 ± 3.30	13.76 ± 3.84	13.22 ± 5.55	9.1 ± 2.77	14.04 ± 3.50	13.22 ± 3.68

SD = standard deviation, CV% = coefficient of variation, 95%CI = 95%confidence interval.

nus floor level at these sites (lesser craniocaudal dimension) compared to the sinus floor level at the site of the 1st premolar. The largest average sinus pneumatization was mesial to the 2nd molar (14.04 ± 3.5 mm), while the average pneumatization around the 1st molar was 9.21 ± 3.3 mm and 13.76 ± 3.84 mm for the left side and 9.1 ± 2.77 mm and 14.04 ± 3.5 mm for the right side relative to the 1st premolar (Table 3).

There was a high correlation between the linear measurements of the right and left sides, where the antroposterior extension of the sinus at level of the nasal floor had the largest correlation ($r = 0.89$). The calculated p-values were all

Table 4 Correlation between linear measurements of right and left sides, and between Simplant and geometric derived maxillary sinus volumes for the same patient. The paired *t*-test was performed for the linear measurements only (sample size = 15). Lt = left; Rt = right; CC = craniocaudal; ML = mediolateral; AP = antroposterior; NS = level of nasal floor; ZG = level of zygomatic complex.

	CC 1st and 2nd premolars	CC 2nd premolar and1st molar	CC 1st and 2nd molars	CC 2nd and 3rd molars	ML at NS	AP at NS	ML at ZG	AP at ZG	Rt side volumetric	Lt side volumetric
Sample size	15	15	15	15	15	15	15	15	5	5
Pearson correlation coefficient (r)	0.88	0.80	0.84	0.84	0.73	0.89	0.86	0.88	0.98	0.96
Student's t-test (p)	0.617	0.715	0.758	0.922	0.675	0.987	0.598	0.606	-	-

P-value significant at $p \leqslant 0.05$.

statistically non-significant denoting lack of difference between the two sides. There was also a high correlation between the Simplant and geometric derived maxillary sinus volumes for both right and left sides (r = 0.98 and 0.96, respectively) (Table 4).

Discussion

The anatomical pneumatization and relations of the maxillary sinus through the alveolar bone are complex, due to the variable extensions of the sinus. The relations between the teeth and the sinus floor are critical elements for diagnosis, dental treatments, and any surgical intervention of dento-antral complex. Several studies have investigated the maxillary sinus volume, dimensions [28,32], and the relative positions of the maxillary sinus to teeth [33,34]. There is a wide range of maxillary sinus dimensions in different studies that may reflect the influential effects like human and race variability and triggering of pneumatization [28,32]. This study was a retrospective one, where 30 sinuses were evaluated. The selected sites for linear measurements were 16 in number giving rise to a total of 240 readings. Increasing the number of readings allowed having average values that were comparable to other studies' results. Moreover, increasing the sample size may attain more generalized values.

The maxillary sinus is anatomically pyramidal in shape with its apex located at the zygoma. This anatomical shape is clearly demonstrated on the 3D volumetric segmentation of the sinus [31]. Accordingly, the linear measurements performed in this study were conducted so that the mediolateral extension represented the height of the maxillary sinus geometrically from its base till its apex, while the antroposterior and the craniocaudal extensions represented the length and the width of the sinus' base.

In this study, it was found that the largest average craniocaudal, mediolateral, and antroposterior extensions of the maxillary sinus using CBCT were 35.54 ± 3.96, 20.43 ± 2.62, and 31.54 ± 3.2 mm, respectively. A comparable average dimension of the sinus was that of Tiwana et al. [11]. They stated that 33 mm high, 23 mm wide, and 34 mm in an anterior–posterior length are the average dimension of the maxillary sinus. Moreover, the analysis of maxillary sinus by the application of high-resolution CT in Shahbazian et al. [17] study revealed that the antroposterior and mediolateral dimensions of maxillary sinus were in the range of 38 mm (SD 5.2) and 23.5 mm (SD 5.1), respectively. Yet, their study did not mention information about the craniocaudal extension of the sinus.

The maxillary sinus in the adult consists of a pyramid shaped cavity with its base at the lateral nasal wall and its apex extending into the zygomatic process of the maxilla [31]. The results obtained in this study revealed that the height of this pyramid (mediolateral) is the smallest dimension, while the antroposterior and craniocaudal dimensions of its base are nearly equal. This result also confirms with that of Tiwana et al. [11].

The results obtained in the current study furthermore assure that the maximum craniocaudal extension of the maxillary sinus was located around the 2nd molar (28 cases out of 30 = 93%). This result strongly matches that of Nimigean et al. [35], who found that the lowest point of the sinus floor was related to the 2nd molar in 93.9% of cases. On the contrary, Koppe et al. [36] found in 50% of the examined skulls that the apices of the upper first and second molars gave rise to prominences on maxillary sinus floor and Ariji et al. [37] showed that the roots of the maxillary first molar were close to the sinus floor in 60% of the studied specimens. The frequency of greatest craniocaudal extension of the maxillary sinus relative to posterior maxillary teeth surfaces was 50% for the distal surface of the 2nd molar, 36% for the mesial side of the 2nd molar, and 3.3% for the mesial side of the 1st molar. A similar relation between the sinus and the teeth with different frequency was that of Killey and Kay [34]. Their frequency of close proximity between the roots of the posterior maxillary teeth and the sinus floor was 45.5% for the 2nd molars, 30.4% for the 1st molars, and 19.7% for the 2nd premolars. Kilic et al. [6] also found that the distance between sinus floor and root tip was longest for the 1st premolar root tip and shortest for the 2nd molar buccodistal root tip for both right and left sides. Moreover, Nimigean et al. [35] concluded that the danger of antral penetration is greater at the level of the buccal roots of the 1st and 2nd molars followed by the 2nd premolar. They also considered these sinusal roots and inferred that variations of the sinus floor's depth can depend on sinuses dimensions, their size, and pneumatization. Variations of the pneumatization of the maxillary alveolar process could take place due to the craniofacial morphological modifications through evolution that is influenced by dentition, chewing force, breathing movements and craniofacial growth factors that also control the pneumatization of the maxillary alveolar processes.

This study showed that the largest average sinus pneumatization was mesial to the 2nd molar (14.04 ± 3.5 mm), while the average pneumatization around the 1st molar was 9.21 ± 3.3 and 13.76 ± 3.84 mm for the left side and 9.1 ± 2.77 and 14.04 ± 3.5 mm for the right side relative to the sinus pneumatization between 1st and 2nd premolars. Unlike most of the studies that estimate sinus pneumatization of alveolar bone relative to the horizontal level of the nasal floor, the present study calculated the sinus pneumatization relative to the highest level of the sinus floor proposed to be located between the 1st and 2nd premolar, where the sinus floor starts to assume a more horizontal level [6]. Although the current study did not calculate the amount of bone remaining between sinus floor and root apices, yet it is obvious that the maximum amount of sinus pneumatization around the 2nd molar obtained in our study goes in agreement with the least amount of bone remaining above the 2nd molar in different studies [6,17,29,35]. The inverse relation between sinus pneumatization and remaining alveolar bone is well known and is further strengthened by Nimigean et al. [35]. Their study inferred that the antral floor depends upon the dental scaffold that constitutes the main factor during development and will transform in relation with the normal/pathological status of the dento-periodontal apparatus, for which they concluded that the available bone is lost from the inferior expansion of the sinus after teeth loss.

In a striking observation, patients' symmetric morphology was clearly evident in the present study. The average linear craniocaudal, antroposterior, and mediolateral measurements were almost bilaterally matching in all cases. A high correlation was found in all 2D linear measurements. The student's paired *t*-test also revealed that there was a non-significant statistical difference between the right and left sides. Shahbazian et al. [17] study revealed symmetric morphology of maxillary sinus in 83% of patients, while the remaining patients (17%) showed a predominant asymmetric morphology. Moreover, Ohba et al. [38] radiologically compared the depth of the sinus floor and did not observe statistical differences between the right and the left sides [37].

In this study, the symmetry between left and right antrum had no doubts. The 3D volumetric measurements of the maxillary sinus obtained for only five patients using the Simplant software highly correlated with the mathematically obtained volumes by the geometric calculation (0.98 for the right and 0.96 for left side). Thus, for 3D volumetric measurements of maxillary sinus, the need for Simplant software should be questioned regarding the cost effectiveness. Although different software's for volumetric analysis seem attractive, illustrative and more diagnostic, yet the geometric method offered a much cheaper, easier, and less sophisticated substitute.

Conclusions

The relations of the sinus floor can be accurately assessed on the different orthogonal images obtained through 3D CBCT scan. The geometric method for volumetric analysis offered a much cheaper, easier, and less sophisticated substitute; therefore, with the availability of software, 3D volumetric measurements are more facilitated.

CBCT showed a great potential for proper preoperative planning and is an indispensable alternative for CT when 3D imaging is mandatory for all dental practitioners. The decision about the imaging technique that is most appropriate for each clinical situation should be based upon the radiation dose, the cost, and the reliability of each technique.

Conflict of interest

The authors have declared no conflict of interest.

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