Maxillary Sinus Dimensions Decrease as Age and Tooth Loss Increase

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ABSTRACT (185 words)

Objective: To investigate the correlation between patient-dependent variables and dimensional variations of the maxillary sinus.

Methods: In this cross-sectional study, a total of 394 individual CBCT scans were evaluated by one calibrated examiner to measure the total volume of the maxillary sinus, the distance between the medial and the lateral wall at 5, 10 and 15 mm vertically from the sinus floor, the height of septa (if present), and the height of the maxillary sinus cavity from the both the alveolar crest and the sinus floor to the meatus. Recorded patient-dependent variables were age, gender and edentulism status.

Results: Total maxillary sinus volume was significantly smaller in completely and partially edentulous patients as compared to dentate subjects. This finding was influenced by age, as older patients exhibited less volume, regardless of gender and edentulism status. Age showed an indirect correlation with the distance to the meatus, the sinus volume and the medio-lateral dimensions. Additionally, the prevalence of accessory meatus in this population was 29.19%.

Conclusions: The dimensions of the maxillary sinus are influenced by age and edentulism status, being reduced by aging and tooth loss.

KEYWORDS*:* maxillary antrum, cone-beam computed tomography, edentulism.

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The maxillary sinuses are two bilateral cavities located within the maxillary bone, lateral to the nasal conchae and below the orbits. They are pyramidal in shape, with the tip located at the zygoma [1], and are the largest of the four paranasal sinuses. The maxillary sinus is coronally bounded by the floor of the orbit, medially by the external wall of the nasal conchae, posteriorly by the pterygoid fossa, anterior and laterally by the alveolar apophysis and floor of the orbit, and, finally, at the inferior level by the alveolar process of the maxillary bone. In some cases, the roots of the posterior teeth are projected into the sinus [2]. Generally, each sinus drains to the nose through the maxillary ostium into the middle meatus. Its surface is lined with the “Schneiderian membrane”, a muco-periosteal bilaminar membrane, with ciliated columnar epithelial cells on the internal side and periosteum on the outside towards the bone. The main purposes of the maxillary sinuses are to reduce the cranium weight, to improve olfactory sense, to warm up the air during the breathing process, to regulate the intranasal pressure [3], and to modulate the quality and properties of the voice [4].

Frequently, regular implant placement for tooth replacement therapy in the posterior maxilla may be limited by insufficient alveolar crest height [5,6]. This observed bone deficiency has been classically described as a consequence of an increased pneumatization of the maxillary sinus following tooth loss [7]. To overcome this anatomical limitation, surgical elevation of the sinus floor to vertically increase the available bone is often indicated. Different maxillary sinus floor elevation techniques have been proposed, including lateral or crestal approaches and the utilization of a wide variety of biomaterials [8–11].

The anatomic features of the maxillary sinus cavity in the three dimensions of space play a crucial role in treatment planning and the execution of the surgical technique [12,13]. In these situations, the use of good diagnostic tools and adequate pre-clinical digital models is required. However, it is yet poorly understood how sinus anatomical changes following tooth loss are determined by patient-dependent factors, such as the presence of septa, age, gender or dental status. The aim of this cross-sectional study was to investigate the correlation that may exist between patient-dependent variables and dimensional variations of the maxillary sinus using cone-beam computed tomography (CBCT) data.

MATERIAL AND METHODS

Population

This cross-sectional study was reviewed and approved by the Ethics Committee for Human Research of the University of Granada (approval number: 46/CEIH/2015). A random sample of 400 CBCTs obtained at the Center for Radiological Diagnosis (Granada, Spain) was retrieved and unlabeled, except for age and gender. Patients were allocated into one of three possible subgroups of edentulism status (D=dentate; PE=partially edentulous; or E=completely edentulous) organized by age and gender. Partially edentulous patients were defined as those missing any tooth by hemi-arcade, excluding third molars.

Cone-beam computed tomography (CBCT)

All samples were captured using the same equipment (Next Generation i-CAT, Imaging Sciences International Inc., Hatfield, PA, USA) and the same settings (120 KVp, 5 mA in complete rotatory mode, a 16x8 cm field of view, with an acquisition time of 8.9 sec and 0.3 mm as voxel size). CBCT images reflecting any movement artifact, evident surgery in the past or deformities in the area were excluded from the analysis.

Radiographic measurements

A proprietary software (i-CAT Vision, Imaging Sciences International, Inc. Hatfield Pennsylvania, USA) was used to obtain measurements related to both sinuses in each patient (R=right; L=left). A calibrated, experienced oral and maxillofacial radiologist (MVT) performed all the measurements. All measurements were repeated twice after at least one week to minimize any measurement bias.

First, all reconstructions were reformatted to position the Frankfurt plane horizontally, and the mid-sagittal plane centered in the coronal and axial planes. Subsequently, the following measurements were performed:

1. Medio-lateral dimensions of the sinus at 5, 10 and 15 mm from the most caudal point of the sinus floor following a coronal section traced at the posterior cortical of the zygomatic apophysis (**Fig. 1**). These vertical thresholds were selected on the basis of clinical significance, since sinus floor augmentation beyond 15 mm is usually not necessary for the placement of regular length implants (i.e. 10 to 12 mm).
2. Presence/absence of accessory meatus, and if was bilateral and/or more caudal than the middle meatus.
3. Distance between the middle meatus (and any accessory, if present) to the most caudal point of the maxillary sinus and to the alveolar crest (**Fig. 2**).
4. The maxillary sinus volume was calculated by importing the DICOM data into the software ViewForum (Philips Healthcare, Best, The Netherlands) and by applying the 3D volume measurement tool (**Fig. 3**).
5. Number, height, location (anterior to the root of the second premolar, between the root of the second premolar and the distal root of the second molar or posterior to the distal root of the second molar) and bilateralism of septa taller than 2.5 mm in a lateral-medial direction [14].

<u>Statistical analyses</u>

All measurements were included into an SPSS database (IBM SPSS Inc., v16.0, Chicago, IL, USA) and analyzed. Given the absence of normal distribution of the medio-lateral measurements (Shapiro-Wilk test), logarithmic transformation of the data was performed to improve normality fitting, and was used for the analysis of variance. Correlations were then explored by Spearman's test. We examined also whether age was non-linearly related to measurements using polynomial regression (up to order 3). Partial correlations used the log-transformed values. Significance was established at an alpha value of 0.05. Unless otherwise noted, values were represented as a mean (SD) in mm.

RESULTS

The sample analyzed consisted of a total of 394 patients after excluding 6 due to the presence of artifacts (4) and previous maxillary sinus floor elevation (2). Of the 394 patients analyzed, 193 (48.98%) were males and 201 (51.02%) females with a mean age of 47.16 (min-max=10-87) years. 106 (26.90%) of them were classified as D, 196 (49.75%) PE, and 92 (23.35%) E. By hemi-arcades, 145 (36.80%) were R-D, 125 (31.75%) R-PE, and 124 (31.47%) R-E, while 159 (40.36%), 118 (28.95%), and 117 (29.70%) were L-D, L-PE, and L-E, respectively. All relevant descriptive data is summarized in **Tables 1-4**.

The intra examiner reliability calculated was 0.97. The analysis on the influence of age in sinus measurements can be summarized as follows: 1) The older the patient, the lower the distance between the most caudal point of the maxillary sinus floor and the middle meatus (rho=-0.166 and rho=-0.113, $p<0.002$ and $p<0.035$, right and left, respectively). Non-linear polynomial regression showed that these relationships can be best described by a third order polynomial (R-square=0.061 and 0.05, $p<0.001$, right and left, respectively), which indicated that distances increased up to 38-46 years, they decreased up to 70 years, and thereafter they stabilized (**Fig. 4**); 2) The older the patient, the lower the volume of the maxillary sinus (rho=-0.249 and -0.186, $p<0.001$, right and left, respectively). Non-linear polynomial regression showed that these relationships can be best described by a third order polynomial (R-square=0.084 and 0.086, $p<0.001$, right and left respectively). Distribution by age intervals follows a pattern similar to the distances to the meatus (**Fig. 5**). 3) The older the patient, the shorter the medio-lateral distance at 10- (rho=-0.152 and -0.143) and 15 mm (rho=-0.246 and -0.216) from the sinus floor ($p<0.005$, right and left, respectively). No improvement of fitting was observed when polynomial regression was used (**Fig. 6**).

In females, shorter distance from the most caudal point of the maxillary sinus to the meatus (31.37 (SD=5.79) vs. 28.08 (SD=5.00) and 31.23 (SD=5.74) vs. 28.03 (SD=4.84), $p<0.001$, male vs. female, right and left, respectively) and less volume (15.72 (SD=5.92) vs. 12.55 (SD=4.86) and 16.08 (SD=6.27) vs. 12.89 (SD=4.84), $p<0.001$), male vs. female, right and left, respectively, were observed.

For the analysis of edentulism, location of the missing teeth (premaxilla, premolars or molars) or specific tooth lost did not show any significant association. However, when categorizing the patients in Dentate, Partially Edentulous or Completely Edentulous, edentulism was inversely correlated with the medio-lateral distance. The 3 (edentulism status, between) x 2 (hemi-arcade, within) x 3 (Distances, within) repeated measures ANOVA of the log transformed distances yield a main effect of edentulism, F(2,368)=4.81, p=0.009, and, as expected, distance, F(2,736)=1390.93, p<0.001. Bonferroni corrected comparisons on the edentulism effect indicated that distances were larger for the D than for the PE (p=0.05) and E (p=0.1) groups, but not between PE and E (p=0.84). The volumes were also associated to edentulism status. The 3 (Dental status, between) x 2 (Hemiarcade, within) ANOVA yielded significant main effect of edentulism status), F(2,322)=0.59, p<0.001). Bonferroni corrected comparisons showed that volumes were larger for D than for PE (p=0.002) and E (p<0.001), but did not differ between them (p=0.50). Finally, the height of septa in anterior location positively correlated with the volume of the sinus (rho=0.116 and 0.135, p<0.022, right and left, respectively).

Partial correlation analysis of age with logarithmic medio-lateral dimensions, controlling by gender and dental status, showed significant lower dimensions at 10- (r=-0.176, -0.118, respectively for right and left) and 15 mm (r=-0.240, -0.215, respectively for right and left) from the sinus floor, and less volume as the age increased (r=-0.124, p<0.03). This latter relationship was particularly interesting as the volume effect was significant only on the right side. The distance to the meatus was reduced as age increased, particularly in partially edentulous patients (r=-0.247, -0.170, p<0.02, right and left), while in the other groups it was not affected by age.

Analysis of the changes in volume in function of age also rendered interesting results when adjusted by edentulism status. The older the patient, the larger the volume in dentate patients (rho=0.245, 0.317, p<0.02, right and left), the smaller the volume in partially edentulous patients (rho=-0.267, -0.233, p<0.004, right and left), while no significant changes in completely edentulous patients were observed (rho=-0.132, -0.180, p>0.11) (**Fig. 7**). Non-linear polynomial yielded very similar results both for meatus and volumes.

Septa prevalence or height was not influenced by age, gender or edentulism status. Correlations between septa prevalence or height with medio-lateral dimensions, distances to the meatus and volume were weakly associated and with no clinically relevant significances.

DISCUSSION

Sinus anatomy determines surgical approach, modifications, potential complications as well as strategies to correct and/or prevent them. It also influences histological outcomes after sinus floor elevation is performed [13]. Therefore, detailed clinical and radiographic evaluation of the posterior maxilla is fundamental when tooth replacement therapy via dental implants is planned. CBCT scans have been widely regarded as the gold standard radiographic test in these clinical scenarios since the information provided surpasses the risks associated with the absorbed radiation doses [15,16]. Furthermore, the accuracy of CBCT for 3D analysis, linear measurements and volume quantification of the sinus have been confirmed by several studies [17,18]. Assessment of anatomic structures in CBCT scans allows for the establishment of quantitative correlations between different variables and measurements, which can be used to minimize the risk of complication and to predict treatment outcomes. In this sense, our group has recently published that the distances from the sinus floor or the alveolar crest to the posterior-superior artery are shorter in partially and completely edentulous patients as well as in women. Also, the medio-lateral width of the sinus increases as those distances decrease [19]. This information reflects the importance of analyzing the relation of the sinus with other variables as it influences the position of relevant anatomical structures.

It had been established that after the extraction of posterior maxillary teeth, the sinus expands in an apico-coronal direction, especially if the roots of the teeth were protruding into the sinus cavity [3]. These and other studies report higher inferior expansion of the sinus when the distance from the tooth root tips to the sinus floor is smaller [2]. Such expansion would increase the risk of oro-antral communications, introduction of foreign bodies, limitation of orthodontic movements or jeopardized implant placement [20]. Sinus pneumatization can be defined as the expansion of the maxillary sinus as a consequence of the end of mechanical stimuli produced by posterior teeth. The maxillary sinus expansion has been said to be caused by "the natural tendency of the maxillary sinus to pneumatize during life" [20]. This tendency is attributed to the increase osteoclastic activity of the Schneiderian membrane and the increase in positive pressure [3,18,21,22]. In addition, the loss of mechanical stimuli exerted by the teeth and the loss of bundle bone after the teeth are extracted leads to the resorption of the alveolar bone [23], which further contributes to the reduction in the available bone. These facts have led to the wrong understanding that the sinus would expand "*sine die*" or that the expansion is of greater magnitude that the resorption of the alveolar process.

From previous studies, it is known that the maxillary sinus dimensions are in the range of the current study in terms of apico-coronal dimensions, complemented with antero-posterior and medio-lateral measurement [20,24,25]. Similarly, the volume was also similar from our study (14.20-14.38 cc) to previously published studies (12.5-15 cc) [24,26,27]. However, in the current study, after analyzing almost 400 patients, negative correlations between age and distance to the meatus (both to the floor of the sinus and to the alveolar crest), medio-lateral dimensions and sinus volume were found. These observations clearly indicate a local collapse of the maxillary bone with age, particularly in corono-apical and lateral-medial directions that result in the reduction of the sinus volume. Contrary to other studies, we have measured the dimensions of the sinus relative to a non-changing anatomical landmark (at the posterior cortical of the zygomatic apophysis of the maxillary bone and middle meatus), which reduces the potential influence of local changes in adjacent teeth or adjacent sinus floor.

There is available literature on maxillary sinus volume and dimensions, relations with posterior maxillary teeth and potential correlations with variables such as race, age, or gender [28]. It has also been reported that the changes in the sinus cavity could be influenced by craniofacial morphological modifications modified by dentition, chewing forces and breathing movements [20] and septa [29,30]. The current study explored the influence of a number of parameters including age, gender, dental status and septa. Contrary to previously reported data [18], the analysis of our data showed an indirect correlation between sinus measurements (medio-lateral distances, distances to the meatus and volume) and tooth loss (i.e., smaller measurements in edentulous patients). Interestingly, controlling by type of edentulism to analyze the influence of age, a similar indirect association of age with maxillary sinus medio-lateral dimensions, distances to the meatus and volume was found. Our data also shows lower linear dimensions and higher volume in dentate patients as the age increase, while partially edentulous patients had less volume and no changes were observed in completely edentulous patients (**Fig. 7**). These observations were particularly significant on the right side. In our opinion, the explanation for these observations is based on 3 aspects: 1) In dentate patients, although a vertical and horizontal collapse is observed with age, the volume is maintained maybe by an antero-posterior expansion (not measured in the current study); 2) When the teeth are lost, there is a lack of stimulation of the maxillary bone that results in a reduction in all measurements, while masticatory activity is maintained by occlusion in the contralateral side; 3) In edentulous patients, once the remodeling processes associated with tooth extraction are completed, no more changes occur with age.

From these observations, a question arises that needs further investigation. Although local factors influence neighboring anatomical structures, it seems clear that function is also a key factor. Interestingly, function highly depends on habits or preferences, such as mastication on one or another side. In contradiction with our findings, previous reports have not found differences between left and right sinuses [20,31], with as much symmetric measurements (non-significant differences between right and left) as in 83% of the patients [25], although less patients were analyzed and not all of these studies classified the patients by edentulism.

CONCLUSION

On the basis of the data analyses hereby presented, it can be concluded that the dimensions of the maxillary sinus are influenced by age and edentulism status. The information generated in the current study could be used to generate pre-clinical digital models of this important anatomical structure.

CLINICAL RELEVANCE: Tooth loss and aging reduce sinus volume and linear dimensions. Therefore, older and edentulous patients are more likely to benefit from expedited tooth replacement therapy shortly after tooth loss has taken place, in order to minimize detrimental anatomic changes that may interfere with an adequate treatment plan execution.

ACKNOWLEDGEMENT: Funding: This investigation was partially supported by Research Groups #CTS-138 and #CTS-583 (Junta de Andalucía, Spain) and by the Andalucía Talent Hub Program from the Andalusian Knowledge Agency, co-funded by the European Union's Seventh Framework Program, Marie Skłodowska-Curie actions (COFUND – Grant Agreement nº 291780) and the Ministry of Economy, Innovation, Science and Employment of the Junta de Andalucía (MPM).

DISCLOSURE: The authors declare no conflict of interest, either directly or indirectly, in any of the products listed in the manuscript.

APPROVAL: All procedures performed in studies involving data from human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. This cross-sectional study was reviewed and approved by the Ethics Committee for Human Research of the University of Granada (approval number: 46/CEIH/2015).

INFORMED CONSENT: Informed consent was waived by the Ethics Committee for Human Research of the University of Granada as the study is a retrospective study with anonymized data.

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LEGENDS

Fig. 1. Representative image of the coronal plane used to measure the medio-lateral size of the sinus at 5, 10 and 15 mm from the most caudal point of the sinus floor.

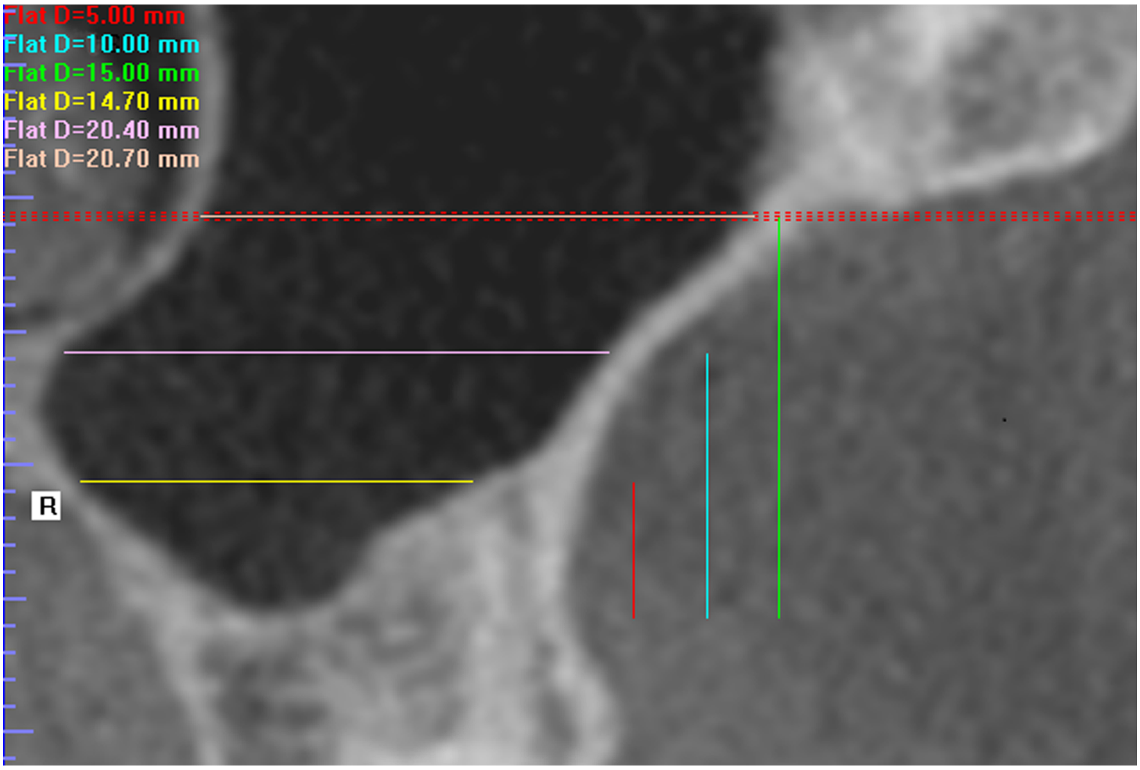

Fig. 2. Representative image of the measurement of the distance between the middle meatus (horizontal red line) and the most caudal point of the maxillary sinus floor (blue vertical line) or the alveolar crest (green vertical line and red dotted line).

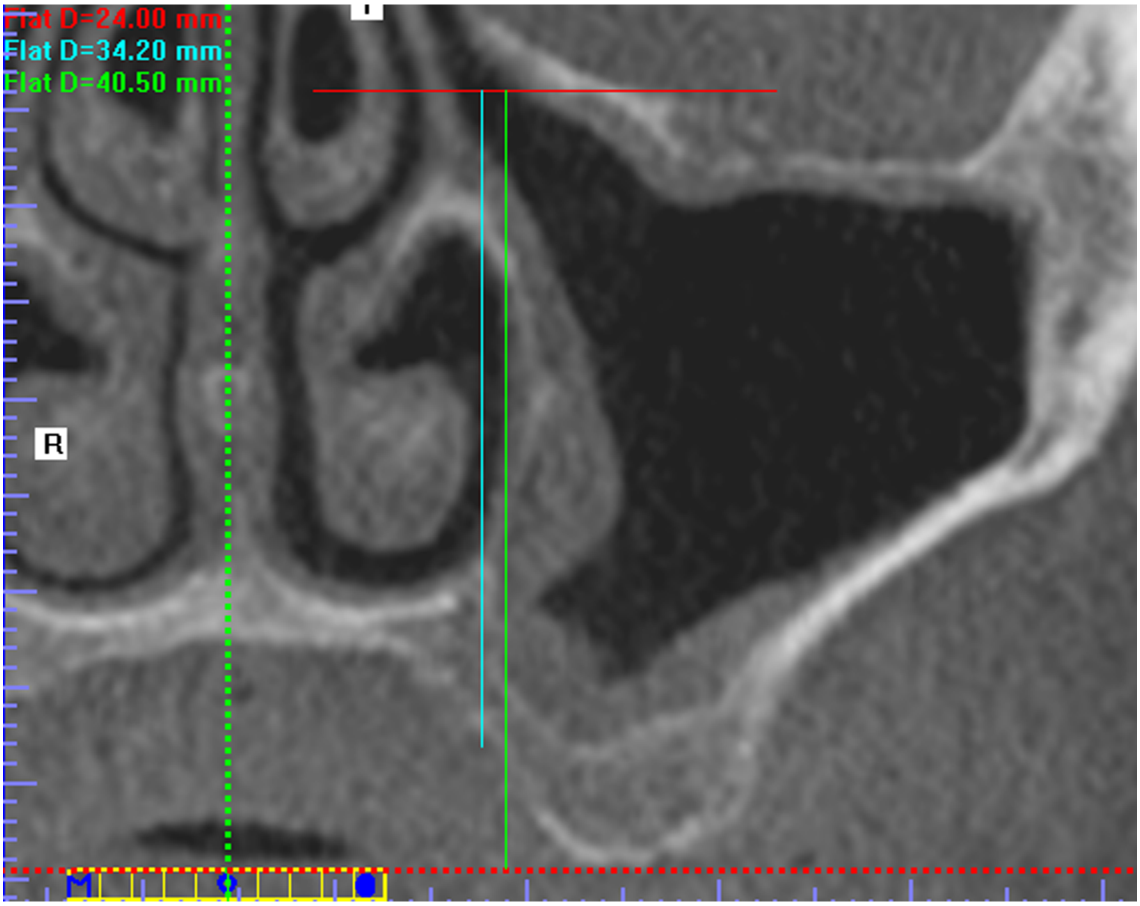

Fig. 3. Representative image of the identification of the sinus limits for the semi-automatic volume quantification. Note that the right sinus has been colored in grey by the software.

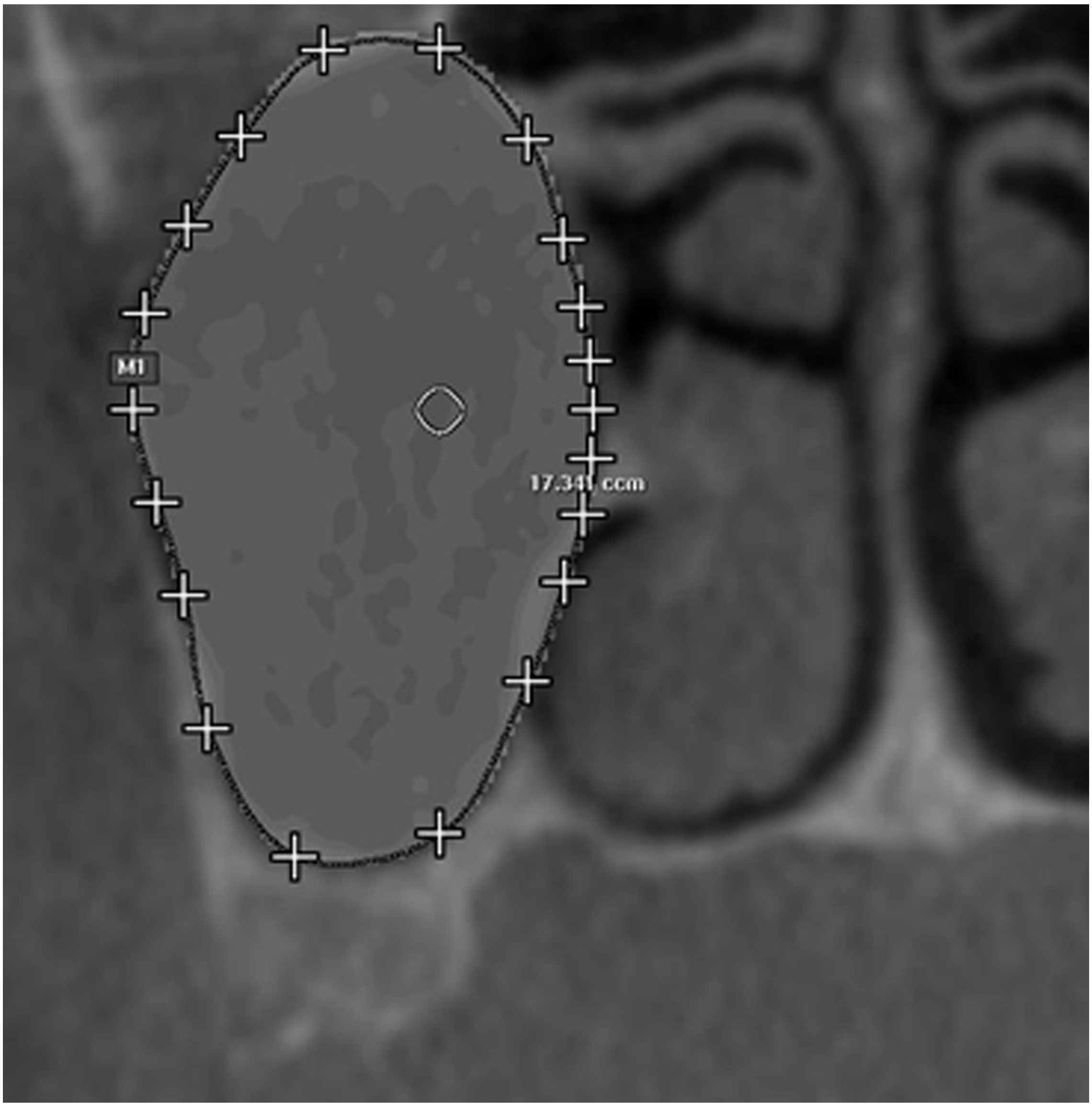

Fig. 4. Change in distance from the most caudal point of the maxillary sinus floor and the middle meatus by age interval (10% percentiles). Note that non-linear polynomial regression showed that these relationships can be best described by a third order polynomial (R-square=0.061 and 0.05, p<0.001, right and left, respectively), which indicated that distances increased up to 38-46 years, they decreased up to 70 years, and thereafter they stabilized.

Figure 4

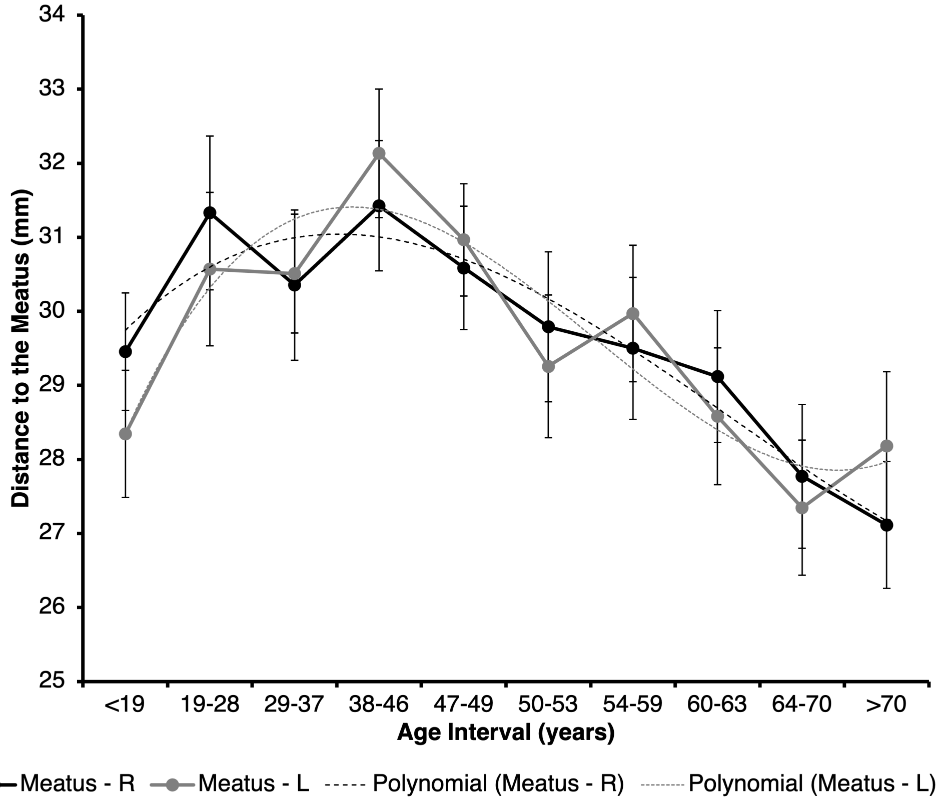

Fig. 5. Change in volume by age interval (10% percentiles). Non-linear polynomial regression showed that these relationships can be best described by a third order polynomial (R-square=0.084 and 0.086, p<0.001, right and left respectively) in a way very similar to distances to the meatus.

Figure 5

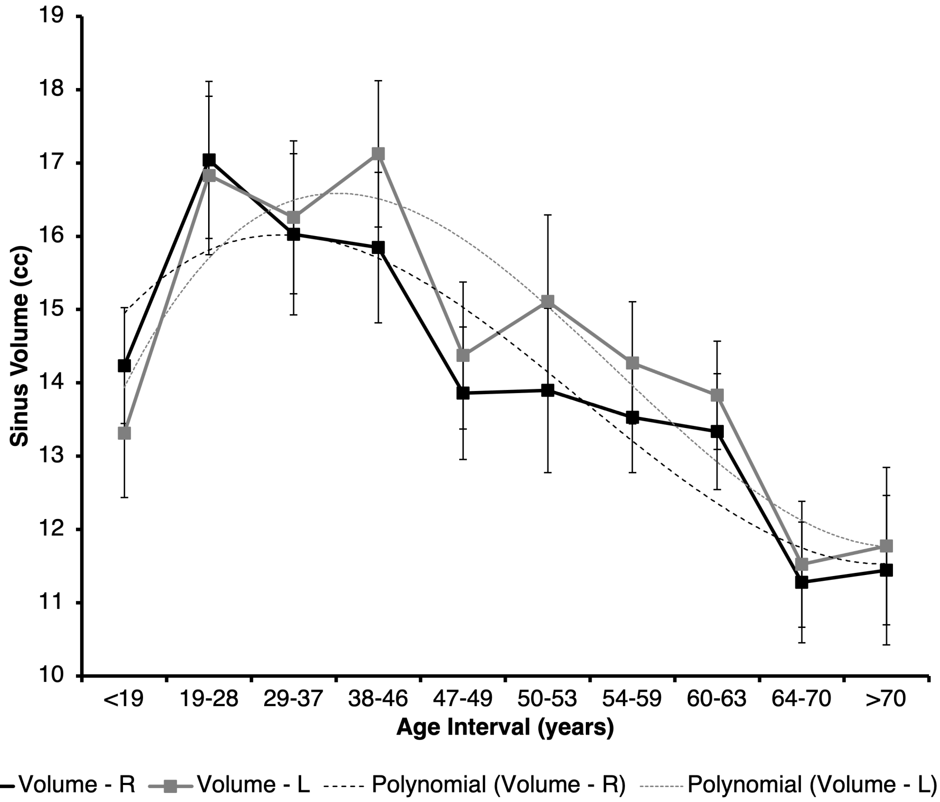

Fig. 6. Change in medio-lateral distances at 5, 10 and 15 mm from the sinus floor by age interval (10% percentiles). No improvement of fitting was observed when polynomial regression was used.

Figure 6

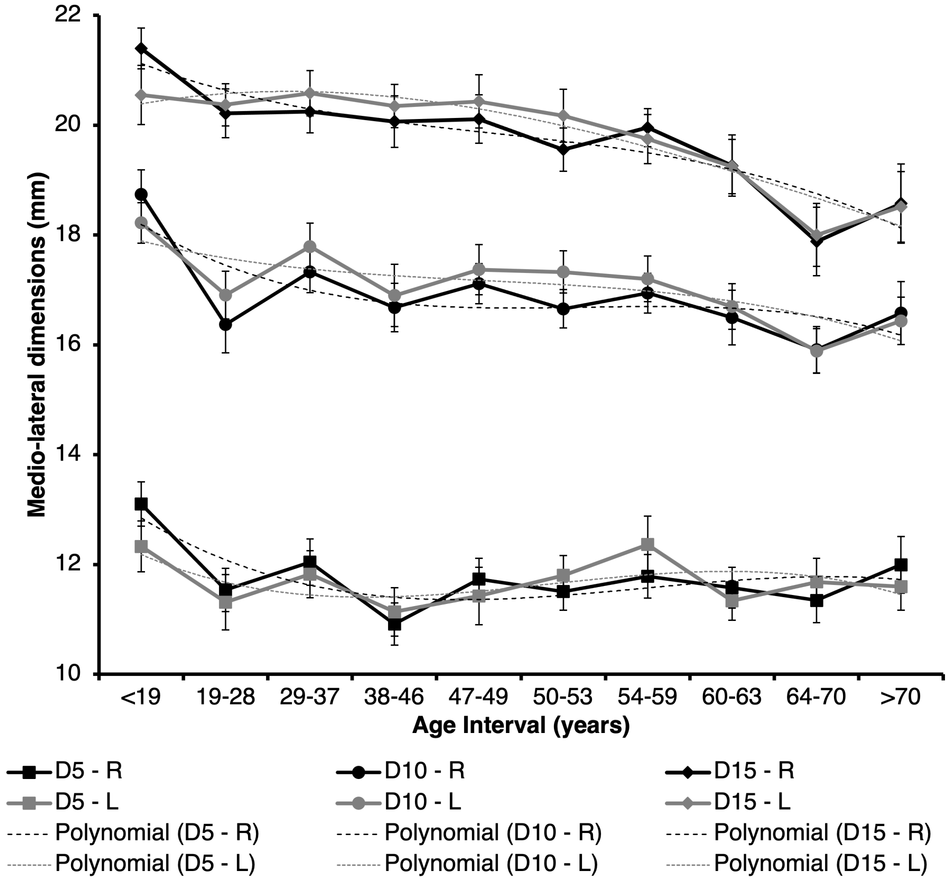

Fig. 7. Associations between age and volume of the maxillary sinus adjusted by dental status (Spearman Rho). Note that positive values correspond with increase in volume as the age increases and the opposite for negative rho values. Only the associations for dentate and partially edentulous patients were statistically significant (*=p<0.02; **=p<0.004).

Figure 7

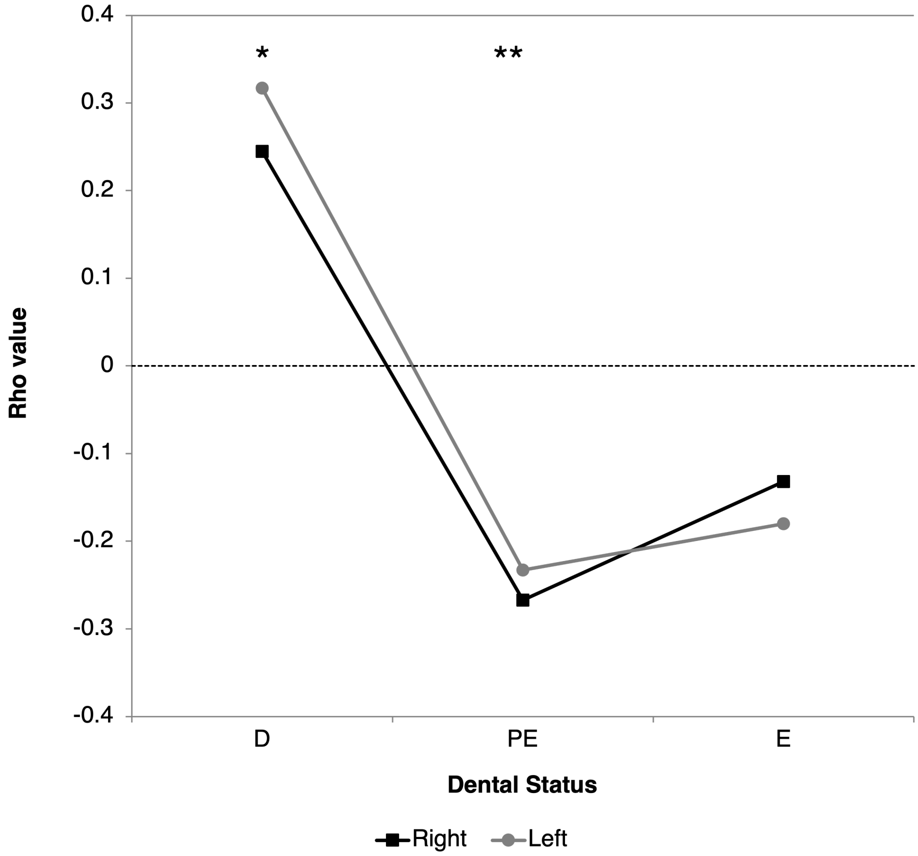

Table 1. Summary of population variables.

Total number of patients		394	
Age		47.16 (10-87)	
Gender			
	Male	193 (48.98%)	
	Female	201 (51.02%)	
Dental status		Right	Left
	Dentate	145 (36.80%)	159 (40.36%)
	Partially edentulous	125 (31.75%)	118 (28.95%)
	Completely edentulous	124 (31.47%)	117 (29.70%)
Septa			
	No	260 (65.99%)	
	1	96 (24.37%)	
	2	33 (8.38%)	
	3	5 (1.27%)	
Location		Right	Left
	Anterior	9	8
	Middle	63	47
	Posterior	22	21

Table 2. Medio-lateral dimensions by distance from the floor and dental status. Values are expressed as mean and standard deviation (in brackets).

Medio-lateral distance		Right	Left
At 5 mm from the floor	TOTAL SAMPLE	11.72(2.65)	
		11.76(2.54)	11.68(2.75)
	Dentate	11.93(2.58)	
		12.13(2.19)	11.74(2.92)
	Partially edentulous	11.74(2.59)	
		11.74(2.56)	11.74(2.62)
	Completely edentulous	11.43(2.83)	
		11.36(2.83)	11.50(2.83)
At 10 mm from the floor	TOTAL SAMPLE	16.98(2.79)	
		16.89(2.83)	17.07(2.75)
	Dentate	17.60(2.63)	
		17.45(2.79)	17.74(2.47)
	Partially edentulous	16.88(2.88)	
		16.87(2.86)	16.89(2.91)
	Completely edentulous	16.46(2.66)	
		16.27(2.72)	16.66(2.59)
At 15mm from the floor	TOTAL SAMPLE	19.75(3.20)	
		19.72(3.20)	19.78(3.20)
	Dentate	20.51(2.57)	
		20.57(2.42)	20.44(2.73)
	Partially edentulous	19.59(3.43)	
		19.56(3.45)	19.63(3.42)
	Completely edentulous	19.20(3.19)	
		19.08(3.27)	19.33(3.12)

Table 3. Measurements to the middle meatus. Values are expressed as mean and standard deviation (in brackets).

Meatus		Right	Left
Distance to sinus floor	TOTAL SAMPLE	29.60(5.57)	
		29.66(5.63)	29.55(5.52
	Dentate	30.49(5.85)	
		30.73(5.97)	30.25(5.74)
	Partially Edentulous	29.66(5.22)	
		29.73(5.19)	29.59(5.26)
	Completely edentulous	28.48(5.82)	
		28.25(5.92)	28.71(5.75
Distance to alveolar crest	TOTAL SAMPLE	38.59(4.43)	
		38.80(4.50)	38.38(4.35)
	Dentate	39.94(4.53)	
		40.23(4.62)	39.65(4.43)
	Partially Edentulous	39.02(3.89)	
		39.22(3.92)	38.80(3.87)
	Completely edentulous	36.17(4.45)	
		36.26(4.54)	36.08(4.38)
Accessory meatus			
	No	279 (70.85%)	
	Yes	115 (29.19%)	

Table 4. Volume by dental status. Values are expressed as mean and standard deviation (in brackets).

		Right	Left
Volume	TOTAL SAMPLE	14.22(5.69)	
		14.05(5.61)	14.40(5.77)
	Dentate	16.19(5.87)	
		16.17(5.48)	16.21(6.26)
	Partially edentulous	13.76(5.26)	
		13.61(5.21)	13.93(5.32)
	Completely edentulous	12.87(5.74)	
		12.48(5.85)	13.25(5.63)