Evaluation of Sinus Pneumatization and Dental Implant Placement in Atrophic Maxillary Premolar and Molar Regions

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Purpose: This study aimed primarily to examine the relationship between maxillary sinus variations and dental implant placement in the atrophic maxillary premolar–molar region. Secondly, the preferences of experienced clinicians with regard to implant length in the bone and sinus were evaluated. ***Materials and Methods:*** The data were collected from panoramic radiographs of patients who had undergone dental implant surgery in the posterior maxilla. Parameters such as sinus pneumatization level, sinus floor elevation operation type, and length of dental implants in the sinus and bone (in millimeters) were evaluated. Groups were created for the categories mild-moderate-medial pneumatization and severe-extreme-medial pneumatization, with the subgroups severe and extreme medial pneumatization for medial pneumatization and "5 to 10 mm" and "≤ 5 mm" for inferior pneumatization of the maxillary sinus. The distribution of the data was evaluated with the Shapiro-Wilk test, and the Mann-Whitney *U* test was used to evaluate the millimeter measurements made in the groups. ***Results:*** The mean implant length in bone tissue was measured as 6.3 mm in the mild-moderate-medial pneumatization group and 5.4 mm in the severe-extreme-medial pneumatization group ($P < .001$), whereas the mean implant length in the sinus was 3.6 mm in the mild-moderate-medial pneumatization group and 3.9 mm in the severe-extreme-medial pneumatization group, respectively ($P < .001$). The mean implant length in the sinus was 3.0 mm in the 5 to 10 mm group and 5.1 mm in the ≤ 5 mm group ($P < .001$), whereas the mean implant length in bone was measured as 6.6 mm in the 5 to 10 mm group and 3.6 mm in the ≤ 5 mm group ($P < .001$). ***Conclusion:*** This was the first study in the literature in which classifications of inferior and medial pneumatization of the maxillary sinus were used for the same implants and their correlation was evaluated in the presence of sinus pneumatization. In this study, the mean implant length in the sinus was measured to be greater as sinus pneumatization progressed medially. Therefore, like inferior pneumatization, medial pneumatization may also have risks attributable to the need for internal or external sinus elevation operations in the atrophic maxilla, and this could be easily underestimated if CBCT is not used. *Int J Oral Maxillofac Implants 2022;37:407–415. doi: 10.11607/jomi.9215*

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Following loss of teeth in the maxillary posterior region, alveolar bone atrophy may be rapid. Several techniques have been used to gain adequate bone and obtain primary stability for osseointegration procedures, such as external or internal sinus elevation and short implants, because the pneumatization may leave only approximately 1 to 2 mm of thin cortical bone between the oral cavity and the maxillary sinus. This is insufficient to provide primary stability and/or osseointegration during dental implant procedures.[1] The external sinus elevation procedure is known to be a more effective technique in terms of bone gain compared with internal sinus elevation; however, it is also a more invasive procedure. Generally, the external sinus elevation technique is performed if the vertical bone height is 4 mm or less, whereas with 5 mm or greater bone height, internal sinus elevation and shorter implants are recommended.[2–4] Furthermore, a recent study of short implants concluded that the cumulative survival rate and marginal bone loss tend to favor the use of short and extra-short implants immediately to restore with fixed prostheses the teeth of partially edentulous patients with severe vertical bone atrophy in posterior areas.[2]

Pneumatization leads the maxillary sinus borders to expand three-dimensionally in the maxillary bone at several crucial anatomical points, including the alveolar crest, anterior region, maxillary tubercule, palatal region, zygomatic bone, and orbital region of the maxillary sinus.[5] Maxillary sinus blood circulation is provided by the posterior superior alveolar and infraorbital arteries. Although these arteries are located in the sinus wall, it must be remembered that they may

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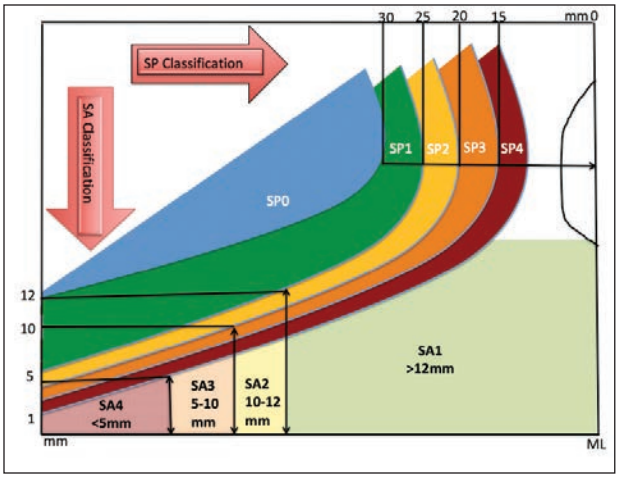

Fig 1 Inferior pneumatization of maxillary sinus and medial pneumatization of maxillary sinus for atrophic posterior maxilla are shown. (Alveolar residual bone height toward inferior aspect, SA1: > 12 mm, SA2: 10–12 mm, SA3: 5–10 mm, SA4: < 5 mm; alveolar residual bone height toward medial aspect, SP0: > 30 mm, SP1: 25–30 mm, SP2: 21–25 mm, SP3: 16–20 mm, SP4: ≤ 15 mm; ML = midline).

show variation.[3] Inferior pneumatization occurring in the alveolar bone and toward the toothless area is one of the most frequent changes in the maxillary sinus.[6] As the expansion through the inferior region proceeds, the medial pneumatization of the maxillary sinus causes unexpected complications, especially during maxillary premolar implant placement, due to lack of proper implant planning. The major predictors of the risk of sinus perforation are reported to be changes in membrane thickness, sinus septa, the presence of teeth, the angle between the buccal and palatal wall, and implants or tooth roots adjacent to the sinus borders.[7] Therefore, the elevation and classification of maxillary sinus pneumatization are challenging issues during implant placement procedures in the atrophic maxilla.

In the literature, several classification methods have become widely accepted, such as the classification of inferior pneumatization of the maxillary sinus (SA) and medial pneumatization of the maxillary sinus (SP). The SA classification was described by Misch et al[8]: 12 mm or more of residual alveolar ridge is classified as SA1; SA2 refers to 10 to 12 mm alveolar bone; and SA3 and SA4 refer to 5 to 10 mm and ≤ 5 mm, respectively. The SA4 classification is ascribed if there is < 5 mm of bone between the crest of the ridge and the maxillary sinus (Fig 1).[8] No patients who had alveolar bone thickness > 10 mm were included in this study because no sinus elevation operations were generally needed to place a dental implant in these cases.

The medial pneumatization of the maxillary sinus (SP) classification was first described by Sicher and DuBrul.[9] In this system, the SP0 (zero) or "clear" (more than 30 mm from the midline) category signifies sinuses that are small and/or high-positioned and not interfering with any implant treatment (clear/no interference to place an implant in any region of the maxilla), whereas SP1 represents a mild degree of enlargement: > 25 mm of alveolar length from the midline to the anterior border of the sinus that can accommodate an upright implant of 7-mm length (about the level of the second premolar). According to this study, SP2 refers to a moderate degree of enlargement: 21 to 25 mm distance from the midline (about the first premolar position); SP3 refers to severe sinus pneumatization: 16 to 20 mm from the midline (canine area). The most extreme medial expansions are observed in SP4, which refers to extreme SP: < 15 mm from the midline to the anterior border of the sinus (Fig 1).[9] In this study, 20 mm was taken to be a risk indicator because severe medial pneumatization was observed when the sinus medial wall and midline were measured as < 20 mm. Also, the SA and SP classification of inferior and medial sinus pneumatization measurements helped in determining the intervals for this study as 5 mm for obtaining the standardization on measurements (Fig 1).

This study aimed first to evaluate the preferences of experienced oral and maxillofacial surgeons for the sinus elevation technique and dental implant placement, given several parameters, in the atrophic alveolar bone in the maxillary premolar–molar region. Second, the risk factors for sinus pneumatization in different types of inferior and medial maxillary sinus pneumatization were determined to aid with dental implant planning using panoramic radiographs.

MATERIALS AND METHODS

Ethical Statement

Ethical approval was given by the local committee of Bezmialem Vakif University, grant number 2011-KAEK-20.01.2020-1311.

Study Design

Data collection. Data on dental implants from five different implant systems were collected from patients who applied to Bezmialem Vakif University, Dentistry Faculty, Oral & Maxillofacial Surgery (OMFS) Department between March 2017 and March 2020. The preoperative and postoperative panoramic radiographs of patients treated with the dental implants in the maxillary premolar–molar region were examined, and the relationships of sinus anatomy and dental implants were evaluated using Romexis Viewer (3.8.3.R, Planmeca). All operations were performed by experienced OMFS surgeons.

Inclusion and exclusion criteria. The inclusion and exclusion criteria are shown in Table 1, and the study plan was carried out after applying these criteria. The study plan is shown in Fig 2.

Table 1 Inclusion and Exclusion Criteria of the Study

Inclusion criteria	Exclusion criteria
Patients between 17 and 70 years of age	Patients under 16 years of age or > 70 years of age
Patients with preoperative and postoperative panoramic dental radiography with sinus-related implants	Patients with only preoperative or postoperative panoramic dental radiography
Patients with sinus-related dental implants placed in ≤ 10 mm of alveolar bone tissue	Patients with sinus-related dental implants placed in > 10 mm of alveolar bone tissue and/or SP0 classification
Similar design of the dental implants in terms of length and diameter. Therefore, Implant A and Implant B dental implants were planned to be included.	Maxillary sinus patients who have undergone surgery due to reasons such as maxillary malignancies or extensive tumors

Evaluated parameters and measurements. Patients were allocated into groups on the basis of measurements of residual alveolar bone height in the inferior pneumatization of the maxillary sinus and measurements of the distance from the midline to the most medial point of the medial pneumatization of the maxillary sinus. For this purpose, medial sinus pneumatization groups were categorized as mild-moderate-medial pneumatization (> 20 mm to midline) and severe-extreme-medial pneumatization (≤ 20 mm to midline). Two subgroups were also created, the severe medial pneumatizaton and extreme pneumatization groups, to evaluate the medial pneumatization at 5-mm intervals. The inferior sinus pneumatization groups were the 5 to 10 mm and ≤ 5 mm groups (Tables 2 to 4). The data recorded for each patient were as follows: sex, follow-up time, sinus pneumatization, sinus floor elevation procedures, the total number of sinus elevation procedures (internal sinus elevation, external sinus elevation, or no sinus elevation), length of dental implants in sinus and bone (mm), implant brand (Implant A for Straumann and Implant B for Bilimplant), bone-level/tissue-level implant preference, prosthetic restoration preference, single crown (SC) or implant-retained bridges (IRBs), inclined/angled implantation at 0 to 15 degrees and 15 to 30 degrees, implant-retained prosthetic restorations, tooth-retained prosthetic restorations, and extreme-medial pneumatization. All measurements were performed on panoramic radiographs as shown in Figs 3a to 3h.

Statistical analysis. Measurements were performed blindly by the same operator (T.G.). Sixty dental implants (10 from each group) were randomly selected and premeasured to assess measurement reliability. The method error results were found to be clinically insignificant ($P > .05$). The distribution of the data was evaluated with the Shapiro-Wilk test, and the Mann-Whitney *U* test was used to evaluate the millimeter measurements made in the groups. Binary comparisons of the parameters in the study that were not measured in millimeters were made using the chi-square test. SPSS (version 15.0, SPSS) was used for the statistical analyses at a significance level of .05.

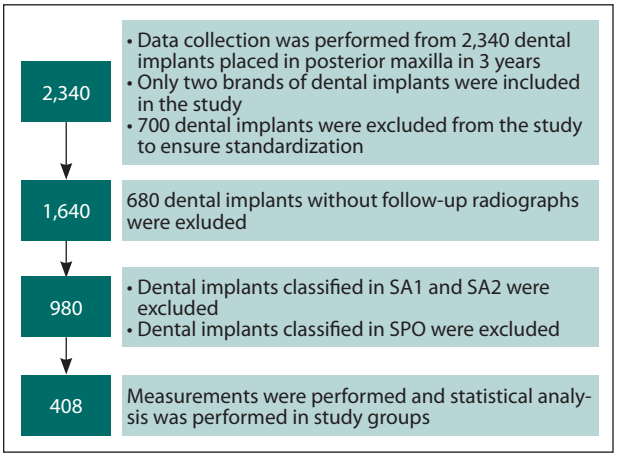

Fig 2 Study plan.

RESULTS

Only Implant A and Implant B dental implants were included in the study to ensure standardization because the diameters, lengths, and bone- or tissue-level implant options were very similar. Dental implants without follow-up radiographs were also excluded. After all inclusion and exclusion criteria were applied to 2,340 dental implants, the final number of implants included in the study was 408 (Fig 2). Eventually, 316 patients (171 women and 145 men) were included in the study. The follow-up period was between 3 and 9 months, and the mean was 4.2 months.

Outcomes for Medial Pneumatization of Maxillary Sinus Groups

Mild-moderate-medial pneumatization and severe-extreme-medial pneumatization groups. A total of 198 implant procedures were performed in the mild-moderate-medial pneumatization group (> 20 mm to midline), whereas 226 implants were placed in the severe-extreme-medial pneumatization group (≤ 20 mm to midline); 387 of 408 dental implants (91.9%) were placed with a sinus elevation procedure (TSL), whereas 15 dental implants (8.1) were placed without sinus elevation (NL). The Mann-Whitney *U* test

Table 2 Outcomes of the Evaluated Parameters from Medial Pneumatization of Maxillary Sinus Groups

	Mild-moderate-medial pneumatization (n = 182)		Severe-extreme-medial pneumatization (n = 226)		Total (n = 408)		*P* value	Severe-medial pneumatization (n = 124)		Extreme-medial pneumatization (n = 98)		Total (n = 222)		*P* value
	n	%	n	%	n	%		n	%	n	%	n	%	
TSL	171	91.9	216	97.3	387	91.9	.01*	132	97.1	84	97.7	216	91.9	NS
ISL	133	71.5	134	60.4	267	71.5	.056	94	69.1	40	46.5	134	71.5	.001*
ESL	38	20.4	82	36.9	120	20.4	.001*	38	27.9	44	51.2	82	20.4	.001*
NL	15	8.1	6	2.7	21	8.1	NS	4	2.9	2	2.3	6	8.1	NS
"5–10 mm"	128	68.8	124	55.9	252	61.8	.007*	83	61.0	41	47.7	124	55.9	.049*
"≤ 5 mm"	58	31.2	98	44.1	156	38.2	.007*	53	39.0	45	52.3	98	44.1	.049*
Implant A	99	53.2	88	39.6	187	45.8	.006*	57	41.9	31	36.0	88	39.6	NS
Implant B	87	46.8	134	60.4	221	54.2	.006*	79	58.1	55	64.0	134	60.4	NS
BL	145	78.0	183	82.4	328	78.0	NS	117	86.0	66	76.7	183	82.4	NS
TL	42	22.0	38	17.6	80	22.0	NS	19	14.0	20	23.3	39	17.6	NS
SC	49	26.3	31	14.0	80	26.3	.002*	114	83.8	77	89.5	191	86.0	NS
IRB	137	73.7	191	86.0	328	73.7	.002*	22	16.2	9	10.5	31	14.0	NS
0–15°	172	92.5	200	90.5	372	92.5	NS	120	88.2	80	93.0	200	90.1	NS
15–30°	14	7.5	21	9.5	35	7.5	NS	16	11.8	6	7.0	22	9.9	NS
F	3	1.6	4	1.8	7	1.6	NS	3	2.2	1	1.2	4	1.8	NS
NT	79	42.5	83	37.4	162	42.5	NS	53	39.0	30	34.9	83	37.4	NS
IRP	66	35.5	76	34.2	142	35.5	NS	46	33.8	30	34.9	76	34.2	NS
TRP	23	12.4	42	18.9	65	12.4	NS	30	22.1	12	14.0	42	18.9	NS
E	18	9.7	21	9.5	39	9.7	NS	7	5.1	14	16.3	21	9.5	0.01*

Mild-moderate-medial pneumatization (> 20 mm to midline) and severe-extreme-medial pneumatization (≤ 20 mm to midline) groups; severe-medial pneumatization (16–20 mm to midline) and extreme-medial pneumatization (≤ 15 mm to midline) groups; and "5–10 mm" and "≤ 5 mm" groups (residual maxillary bone height), total number of sinus lifting (TSL) procedures, internal sinus lifting (ISL), external sinus lifting (ESL), or no sinus lifting (NL), length of dental implants in sinus and bone (mm), implant brands named as Implant A and Implant B, bone-level (BL)/tissue-level (TL) implant preference, prosthetic restoration preference; single crown (SC) or implant-retained bridges (IRB), inclined/angled implantation with 0–15° and 15–30°, failure (F), natural teeth (NT), implant-retained prosthetic restorations (IRP), tooth-retained prosthetic restorations (TRP), extreme-medial pneumatization (E). *Statistically significant, $P < .05$, NS = non-significant.

Table 3 Outcomes of the evaluated parameters from the inferior pneumatization of maxillary sinus groups

	"5–10 mm" (n = 252)		"≤ 5 mm" (n = 156)		Total (n = 408)		*P* value
	n	%	n	%	n	%	
TSL	232	92.1	155	99.4	387	94.9	.001*
ISL	190	75.5	77	49.4	267	65.4	.01*
ESL	42	16.7	78	50.0	120	29.4	< .001*
NL	20	8.2	1	0.6	21	5.1	NS
Implant A	127	50.4	60	38.5	187	45.8	.01*
Implant B	125	49.6	96	61.5	221	54.2	.01*
BL	204	81.0	124	79.5	328	80.4	NS
TL	48	19.0	32	20.5	80	19.6	NS
SC	53	21.0	27	17.3	80	19.6	NS
IRB	199	79.0	129	82.7	328	80.4	NS
0–15°	229	90.9	143	91.7	372	91.2	NS
15–30°	22	8.7	13	8.3	35	8.6	NS
F	5	2.0	2	1.3	7	1.7	NS
NT	99	39.3	63	40.4	163	39.7	NS
IRP	86	34.1	56	35.9	142	34.8	NS
TRP	43	17.1	22	14.1	65	15.9	NS
E	24	9.5	15	9.6	39	9.6	NS

"5–10 mm" and "≤ 5 mm" groups (residual maxillary bone height) and total number of sinus lifting (TSL) procedures, internal sinus lifting (ISL), external sinus lifting (ESL) or no sinus lifting (NL), length of dental implants in sinus and bone (mm), implant brands named as Implant A and Implant B, bone-level (BL)/tissue-level (TL) implant preference, prosthetic restoration preference; single crown (SC) or implant-retained bridges (IRB), inclined/angled implantation with 0–15° and 15–30°, failure (F), natural teeth (NT), implant-retained prosthetic restorations (IRP), tooth-retained prosthetic restorations (TRP), extreme-medial pneumatization (E). *Statistically significant, $P < .05$, NS = non-significant.

Table 4 Outcomes of Dental Implant Length Measurements in Sinus and Bone in All Groups

	Dental implant length (mm)				
	Group "5–10 mm" (n = 252)		Group "≤ 5 mm" (n = 156)		
	Mean	SD	Mean	SD	*P* value
In sinus	3.0	1.5	5.1	1.9	< .001*
In bone	6.6	1.2	3.6	0.9	< .001*
	Group mild-moderate-medial pneumatization (n = 182)		Group severe-extreme-medial pneumatization (n = 226)		
	Mean	SD	Mean	SD	*P* value
In sinus	3.6	2.1	3.9	1.9	.25
In bone	6.3	1.9	5.4	1.7	< .001*
	Group severe-medial pneumatization (n = 124)		Group extreme-medial pneumatization (n = 98)		
	Mean	SD	Mean	SD	*P* value
In sinus	3.7	1.8	4.3	2.0	.001*
In bone	5.6	1.6	5.0	1.8	.02*

Statistically significant; $P < .05$.

was used to evaluate the millimeter measurements made in these two groups, and the results of this test are shown in Table 4. In the mild-moderate-medial pneumatization group, the mean implant length in the sinus was 3.6 mm, while in the severe-extreme-medial pneumatization group, this average was found to be 3.9 mm ($P = .25$). The mean implant length within the bone was 6.3 mm in the mild-moderate-medial pneumatization group and 5.4 mm in the severe-extreme-medial pneumatization, and this difference was also statistically significant ($P = .001$).

Binary comparisons of the parameters in the study that were not measured in millimeters were made using the chi-square test, and the results are shown in Table 2. 267 internal sinus elevations and 120 external sinus elevations were performed in the mild-moderate-medial pneumatization and severe-extreme-medial pneumatization groups, and statistically significant differences were observed between the groups ($P = .01$). Internal sinus elevation procedures were performed before 133 dental implants (71.5%) in the mild-moderate-medial pneumatization group, and 134 (60.4%) in the severe-extreme-medial pneumatization group ($P = .056$). The number of external sinus elevation procedures before dental implant placement was 38 (20.4%) in the mild-moderate-medial pneumatization group, whereas 82 (36.9%) external sinus elevation operations were performed in the severe-extreme-medial pneumatization group ($P = .001$).

The study included an evaluation of whether the dental implants were loaded with IRBs or SCs for prosthetic restoration, regardless of the type of tooth (premolar or molar). In this context, statistically significant differences were observed in the medial pneumatization of maxillary sinus groups (mild-moderate-medial pneumatization and severe-extreme-medial pneumatization). The preference for an IRB in both groups was high (at least 73.7%); however, the rate of SC placement was 26.3% in the mild-moderate-medial pneumatization group, whereas in the severe-extreme-medial pneumatization group, this rate was 14% ($P = .002$). Therefore, the rate of IRB placement was significantly greater in the severe-extreme-medial pneumatization group (86%) than in the mild-moderate-medial pneumatization group (73.7%; $P = .002$). There were no significant differences in other parameters in the study.

Severe-medial pneumatization and extreme-medial pneumatization groups. A total of 222 dental implants were evaluated: 124 dental implants were in the severe-medial pneumatization (16 to 20 mm to midline) group, and 98 dental implants were in the extreme-medial pneumatization (≤ 15 mm to midline) group. The Mann-Whitney *U* test was used to evaluate the millimeter measurements made in these two groups, and the results of this test are shown in Table 4. In the severe-medial pneumatization group, the mean implant length in the sinus was 3.6 mm, while in the extreme-medial pneumatization group, it was 4.3 mm ($P = .001$). The mean implant length within the bone was measured as 5.6 mm in the severe-medial pneumatization group and 5.0 mm in the extreme-medial pneumatization group, and this difference was also statistically significant ($P = .02$).

Binary comparisons of the parameters in the study that were not measured in millimeters were made using the chi-square test and are shown in Table 2. In total, 134 internal sinus elevations and 82 external sinus elevations were performed in the severe-medial pneumatization

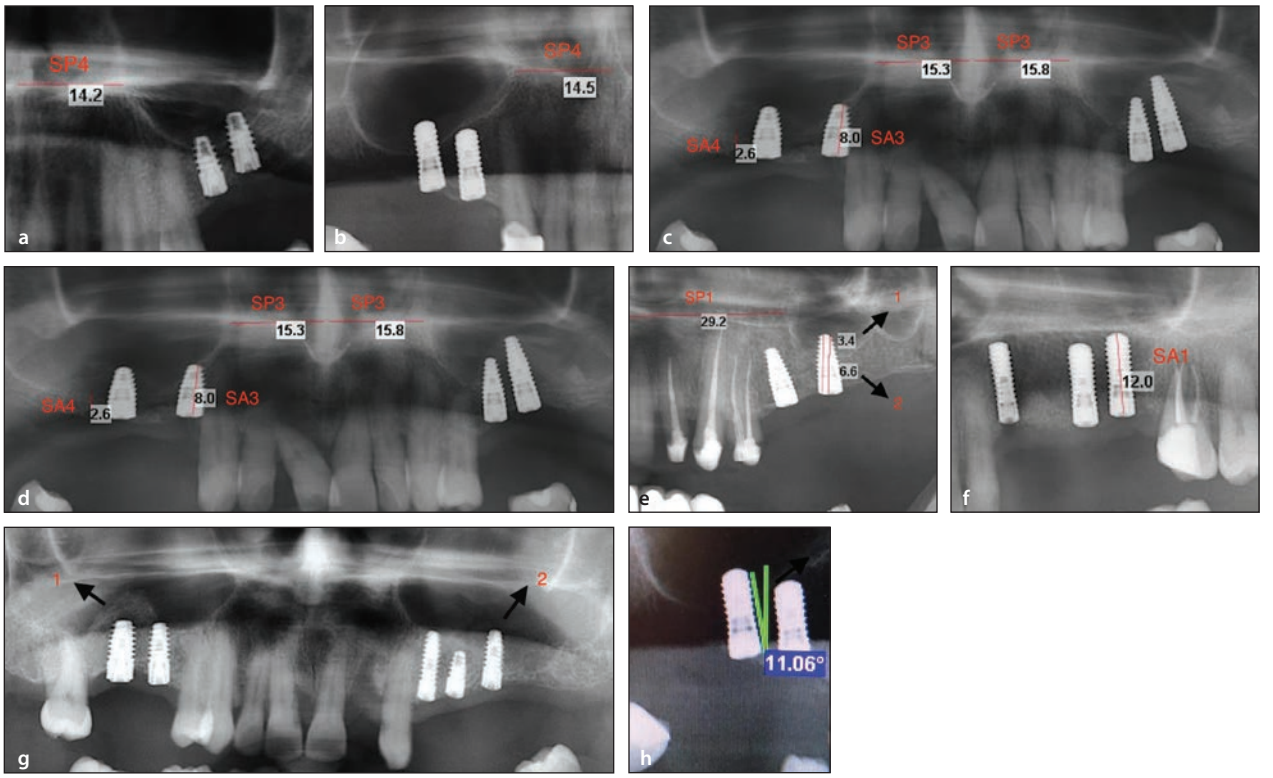

Fig 3 Inferior pneumatization of maxillary sinus and medial pneumatization of maxillary sinus are shown; the measurements (in millimeters) of the dental implants in bone and sinus were made from panoramic radiographs. *(a)* SA4 classification. *(b)* SA4 classification. *(c)* SP2, SP3, and SA2 classifications in the same patient, length measurements for dental implants. *(d)* SP3, SA3, and SA4 classifications in the same patient, length measurements for dental implants. *(e)* SP1 and length measurements for dental implants, 1: length measurement in the sinus, 2: length measurement in bone. *(f)* SA1 classification. *(g)* 1: External sinus elevation, 2: internal sinus elevation. *(h)* Angle measurement for dental implants; black arrow indicates the parallel line to the midline, whereas the other line indicates the axis of the implant.

and extreme-medial pneumatization groups. A statistically significant difference was observed between the severe-medial pneumatization and extreme-medial pneumatization groups in terms of internal sinus elevation procedures: They were performed before 94 dental implants (69.1%) in the severe-medial pneumatization group, while the number was 40 (46.5%) in the extreme-medial pneumatization group ($P = .001$). A significant difference was also observed in external sinus elevations between the severe-medial pneumatization and extreme-medial pneumatization groups, where 44 external sinus elevations (51.2%) were performed in the extreme-medial pneumatization group and 38 (27.9%) in the severe-medial pneumatization group ($P = .001$).

Outcomes for Inferior Pneumatization of Maxillary Sinus Groups

5 to 10 mm and ≤ 5 mm groups. Statistical analysis was performed for 408 dental implants, of which 252 were in the 5 to 10 mm group and 156 were in the ≤ 5 mm group. In the 5 to 10 mm group, 267 internal sinus elevations and 120 external sinus elevations (TSLs = 387) were performed before dental implant placement. NL was 21, of which 20 were in the 5 to 10 mm group and just one dental implant was in the ≤ 5 mm group. The Mann-Whitney *U* test was used to evaluate the millimeter measurements made in these two groups, and the results of this test are shown in Table 4. The mean implant length in the sinus in the 5 to 10 mm group was 2.9 mm, compared with 5.2 mm in the ≤ 5 mm group ($P < .001$). For implant length measurements within the bone, the mean was 6.8 mm in the 5 to 10 mm group and 3.8 mm in ≤ 5 mm ($P < .001$).

Binary comparisons of the parameters in the study that were not measured in millimeters were made using the chi-square test and are shown in Table 3. Statistically significant differences were observed between the severe-medial pneumatization and extreme-medial pneumatization groups in terms of internal sinus elevation procedures: They were performed before 190 dental implants (75.5%) in the 5 to 10 mm group and 77 (49.4%) in ≤ 5 mm group ($P = .01$). A significant difference was also observed in external sinus elevations between the 5 to 10 mm and ≤ 5 mm groups: 78 external sinus elevations (50%) were performed in the ≤ 5 mm group and 42 (16.7%) in the 5 to 10 mm group ($P < .001$).

Another significant difference was found between the classifications for inferior pneumatization of the maxillary sinus, shown in Table 2. The results reveal that the 5 to 10 mm classification was significantly higher in

the mild-moderate-medial pneumatization (> 20 mm to midline) group than in the severe-extreme-medial pneumatization (≤ 20 mm to midline) group ($P = .007$), and also significantly higher in the severe-medial pneumatization (16 to 20 mm to midline) group than in the extreme-medial pneumatization (≤ 15 mm to midline) group ($P = .049$). The ratio of ≤ 5 mm classifications was also significantly higher in the severe-extreme-medial pneumatization group than the mild-moderate-medial pneumatization group ($P = .007$), and significantly higher in the extreme-medial pneumatization group than in the severe-medial pneumatization group ($P = .049$).

DISCUSSION

Sinus pneumatization in the premolar region is generally underestimated compared with the molar region. This could be because large defects in the alveolar bone after molar teeth extractions may lead to more inferior sinus movement compared with premolar teeth.[10] However, maxillary posterior atrophic bone and sinus pneumatization causes extra difficulties for dental implant surgery protocols because of the exposed sinus membrane, increased morbidity rates, additional cost, surgeries, etc.[11,12] Although there is no consensus, it is known that if the residual bone height is < 4 to 5 mm, a one- or two-stage sinus elevation operation is recommended, with a lateral technique. An alternative, to avoid the sinus augmentation procedure, is to place medially or distally angulated implants in the sinus cavity in the presence of sufficient bone height.[13] Moreover, short dental implants are also used as an alternative treatment in such cases; therefore, clinicians are encouraged to prefer these implants in their clinical practice.[2]

Various treatment options have been used to overcome problems of insufficient bone quantity in the posterior maxilla, such as internal sinus elevation and external sinus elevation or their combinations.[14] The most conservative option is the use of short implants (≤ 6 mm), to avoid placing the implant in the sinus cavity.[2,15] However, Papaspyridakos et al stated that short implants were found to have higher variability and lower predictability in terms of survival rates compared with longer implants (> 6 mm) after periods of 1 to 5 years in function.[16] Moreover, short implants in function for more than 3 years presented higher failure rates than short implants in function for < 3 years. The authors also recommended splinting crowns supported by short implants in the posterior area, and such short implants are a valid option for selected cases given their relatively high long-term survival rates.[17] In the present study, the operators preferred not to use short implants where they predominantly performed sinus elevation operations: 387 of 408 implants (91.9%) were placed after a sinus elevation operation in the groups with inferior pneumatization of the maxillary sinus (5 to 10 mm and ≤ 5 mm groups; $P = .01$).

The 5 to 10 mm group was mostly suitable for short implant placement, but the mean dental implant length within the bone was 6.84 mm in the 5 to 10 mm group and 3.83 mm in the ≤ 5 mm group ($P < .001$). The operators preferred internal sinus elevation procedures over external sinus elevations in the 5 to 10 mm group ($P = .01$). The mean implant length in the sinus in the 5 to 10 mm group was 2.94 mm, vs 5.23 mm in the ≤ 5 mm group ($P < .001$). The total number of sinus operations was 387, and only 21 dental implant placements were performed without a sinus operation ($P = .001$). It is evident that short implants were not trusted by the operators in this study, who were experienced in the oral and maxillofacial surgery field.

This outcome could be due to a lack of trust among the surgeons, but considerations regarding the prosthesis could also play a significant role in their preferences. The rate of IRB was 80.4%, whereas the SC rate was 19.6% for all dental implants. Statistically significant results were also observed for the IRB parameter between the mild-moderate-medial pneumatization and severe-extreme-medial pneumatization groups: 86% of all implants were loaded with IRB, whereas 14% were loaded with SC ($P = .002$). Therefore, the preferences for dental implant length appear to be influenced by the type of restoration applied.

To ensure that maxillary sinus floor elevation is an effective procedure, as stated during The Sinus Consensus Conference and confirmed by numerous other consensus conferences, it is mandatory to examine the presurgical sinus conditions carefully. Especially during medial pneumatization, operators should not focus directly on the patency of the ostium in the radiologic evaluation before performing a sinus elevation, because many anatomical features can influence the surgical approach of sinus floor elevation. During this process, the shape of the maxilla becomes pyramidal, with a base formed from the nasal wall and with the apex spreading into the zygomatic process of the maxillary bone.[7] The maxillary sinus is considered flexible because its walls can expand and compress in response to internal or external pathologic processes.[6] In an anatomical study, Sicher and DuBrul stated that the normal distance measurement at the level of the lateral incisor would be approximately 10 mm, compared with 25 mm at the level of the first premolar from the midline.[9] However, the relationship between the maxillary premolar region and the sinus was not stated as the primary consideration before dental implant planning; in the present study, it was observed that medial pneumatization is also crucial when deciding on the surgery and treatment plan, especially in the presence of atrophic alveolar bone. In addition, it has been reported that maxillary sinus

hypoplasia should be evaluated carefully prior to any sinus surgery to avoid surgical complications.[18] It can be concluded that the risk of the operation increases throughout the posterior maxilla because the height of the residual bone was significantly lower in the groups with more medially pneumatized maxillary sinuses. In this study, it was shown that the severe-extreme-medial pneumatization group revealed lower residual bone height than the mild-moderate-medial pneumatization group ($P = .007$), whereas the extreme-medial pneumatization group also revealed significantly lower scores than the severe-medial pneumatization group ($P = .049$). However, because the level of statistical significance was not considered high enough between the severe-medial pneumatization and extreme-medial pneumatization groups ($P = .049$), further studies with the inclusion of larger samples are recommended.

Moreover, the mild-moderate-medial pneumatization and severe-extreme-medial pneumatization groups revealed statistically significant differences in crucial sinus elevation operation parameters, in which the severe-medial pneumatization and extreme-medial pneumatization groups were also significantly different (Table 2). For example, the rate of external sinus elevation was significantly higher in the severe-extreme-medial pneumatization group than in the mild-moderate-medial pneumatization group ($P = .001$) and significantly higher in the extreme-medial pneumatization group than in the severe-medial pneumatization group ($P = .001$). Although internal sinus elevation scores were not significantly higher in the severe-extreme-medial pneumatization group than in the mild-moderate-medial pneumatization group ($P = .056$), the difference was statistically significant between the severe-medial pneumatization and extreme-medial pneumatization groups ($P = .001$). One of the most promising results of the study was the statistically significant difference in the "≤ 5 mm" classification ratio of all dental implants in the medial pneumatization of maxillary sinus classifications. In addition, Tolstunov et al noted an inverse correlation between medial sinus pneumatization and the total mean maxillary bone volume.[19] Therefore, it may be stated that as medial pneumatization increases, atrophy of the maxillary residual bone toward the inferior region also increases. Moreover, the authors believe that significantly different scores would have been found in the severe-medial pneumatization and extreme-medial pneumatization groups if more dental implants in the severely atrophic posterior maxilla (≤ 5 mm group) were included in further studies. These results are also supported by the other analyses shown in Table 4. According to this table, almost all the analyses were statistically significant in terms of the dental implant length in the bone and sinus. A nonsignificant difference was only observed for dental implant length in the sinus between the mild-moderate-medial pneumatization and severe-extreme-medial pneumatization groups ($P = .25$). To the authors' knowledge, this is the first study in the literature in which classifications of both inferior and medial pneumatization of the maxillary sinus were used for the same implants and their correlation was evaluated in the presence of sinus pneumatization. However, CBCT is known to be a more appropriate diagnostic tool for implant planning, and the authors acknowledge that its absence is a limitation. Nevertheless, the results were promising and gave insights into the literature concerning the classification of atrophy in maxillary posterior regions with two-dimensional radiographs such as panoramic radiographs. Moreover, it is noted that the oral and maxillofacial surgeons in this study were still biased against short implants in their clinical practice. Although it has been proven that the survival rates of short implants are not significantly different from those of longer implants, the present analysis did not yield similar outcomes.

In general, implant failure rates are examined with regard to the placement of the implant in the posterior region of the maxilla, attention to the excellent prosthetic position of the implants, and the need for vertical ridge augmentation.[20] Dental implants used with major bone grafts generally have lower survival rates.[21–24] Prerequisites for successful and long-term results are the assurance and maintainance of implant stability. One of the major limitations of this study is that the follow-up period was only 4.2 months; however, the study aimed to evaluate the preferences of the operators in treating the atrophic posterior maxilla with different sinus variations. The overall follow-up period was adequate to evaluate the prosthetic restorations, but the overall success was not presented as an outcome because the authors believe that the rate will probably change. Failure was observed in 7 of 408 dental implants.

Another limitation might be that the study was performed with two different brands of implants. It is known that differences in the design of dental implants affects some parameters, for example, increased retention during recovery time, provision of primary stabilization, and minimizing the tension that may occur between the implant and jaw bone.[25,26] Many authors have reported that a degree of surface roughness improves implant performance at various levels.[27–29] In the present study, significant differences were observed between the surgeons' preferences for brands; however, the numbers of each brand of implant used were similar. One of the reasons that the study plan was created with these two brands was their similar designation in terms of width and lengths, surface properties, and application protocols. Implant B dental implants were preferred more in the severe-extreme-medial pneumatization and ≤ 5 mm groups ($P = .006$), whereas

implant A dental implants were more preferred in the mild-moderate-medial pneumatization and 5 to 10 mm groups ($P = .01$). This outcome does not refer to any superiority of one brand over another, and further studies are required to investigate this issue.

CONCLUSIONS

To the authors' best knowledge, this study is the first of its kind, in which the relationship between inferior pneumatization of the maxillary sinus and medial pneumatization of the maxillary sinus were evaluated, measured, and reported simultaneously for each dental implant through several parameters. The OMFSs in this study frequently preferred a sinus elevation operation (92%) when the alveolar bone height was adequate for short implants (≤ 6 mm).

It is also concluded that it seems crucial to include medial pneumatization of the maxillary sinus during preevaluation of dental implant placements in the posterior region of the maxilla, because atrophic alveolar bone in the maxillary premolar and molar region was significantly correlated with medial sinus pneumatization, and this effect is likely to be underestimated in panoramic radiographies. Therefore, CBCT is highly recommended in dental implant planning, especially in cases of severe and extreme medial sinus pneumatization, and when the atrophic alveolar bone height is < 5 mm.

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