Maxillary Sinus Pneumatization Following Extractions: A Radiographic Study

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Purpose: *The aim of this study was to identify and measure postextraction maxillary sinus pneumatization using fixed reference lines on panoramic radiographs.* ***Materials and Methods:*** *One hundred fifty-two panoramic radiographs, each of a different subject, were used to measure superoinferior differences of the sinus floor position in dentate sites in comparison with contralateral edentulous sites. Fifty-eight pairs of panoramic radiographs, each pair of the same subject, were used to measure superoinferior differences of the sinus floor position in the same site before and 6 to 67 months after extraction. All measurements were performed using an interorbital line and 2 zygomatic process lines as reference lines. Statistical correlations between the amount of expansion of the sinus and the root classification, projection length, duration after extraction, type, and number of the extracted teeth were examined.* ***Results:*** *Postextraction expansion of the sinus in an inferior direction occurred in both comparisons (2.18 ± 2.89 mm for dentate versus contralateral sites and 1.83 ± 2.46 mm for the same site pre- and postextraction). A considerable amount of expansion occurred after the extraction of teeth surrounded by a superiorly curving sinus floor (5.27 ± 1.59 mm). A larger expansion was also measured after second molar extractions in comparison to first molars and in cases of extractions of 2 or more adjacent posterior teeth.* ***Discussion:*** *Posterior maxillary tooth extraction caused an inferior expansion of the maxillary sinus in relation to fixed anatomic landmarks, thus proving the pneumatization phenomenon after tooth loss.* ***Conclusions:*** *Sinus pneumatization was identified after extraction of maxillary posterior teeth. The expansion of the sinus was larger following extraction of teeth enveloped by a superiorly curving sinus floor, extraction of several adjacent posterior teeth, and extraction of second molars (in comparison with first molars). If dental implant placement is planned in these cases, immediate implantation and/or immediate bone grafting should be considered to assist in preserving the 3-dimensional bony architecture of the sinus floor at the extraction site.* Int J Oral Maxillofac Implants 2008;23:48–56

Key words: *extraction, maxillary sinus, panoramic radiograph, pneumatization, sinus floor topography*

Pneumatization is a physiologic process that occurs in all paranasal sinuses during the growth period, causing them to increase in volume.[1,2] The maxillary sinus is the largest of the paranasal sinuses and, at 10 weeks in utero, is the first to develop. After birth, the sinus continues to pneumatize into the developing alveolar ridge as the permanent teeth erupt. At 12 to 13 years, the sinus floor is level with the nasal floor, and at age 20, with the completion of the eruption of the third molars, the pneumatization of the sinus ends, and the sinus reaches 5 mm inferior to the nasal floor.[3–5] Studies comparing the maxillary sinus volume between the right and left sides have not found statistically significant differences.[2,6]

Histologic examination has shown that the pneumatization process occurs by osteoclastic resorption of the cortical walls of the sinus and the layering of osteoid inferior to it.[7] The reasons for sinus pneumatization are poorly understood. Among the factors that influence this process are heredity,[1,8] the pneumatization drive of the mucous membrane of the nose,[2] craniofacial configuration,[9] density of the bone,[9] growth hormones,[9] sinus air pressure,[2,10,11] and sinus surgery.[12]

Few experimental studies describe a resumption of maxillary sinus pneumatization in adults after posterior tooth extraction.[13–16] The cause for this phenomenon, also referred to as the fourth expansion phenomenon of the maxillary sinus,[3] has been explained as a type of disuse atrophy[13,17]—the

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decrease of functional forces transferred to the bone after tooth loss causes a shift in the remodeling process toward bone resorption according to Wolff's law.[3] This results in an increase of the sinus volume at the expense of the edentulous alveolar ridge. The rate and degree of the pneumatization process after tooth loss may be influenced by

1. The protrusion of tooth roots into the sinus cavity.[13] Roots that protrude into the sinus have a thin cortical bone lining.[7] During extraction this thin bone may break and dislocate, thus allowing the sinus to expand toward the empty socket.
2. Molar extraction. Greater pneumatization has been found after molar extraction in comparison to premolar extraction.[13] The reason may be the large defect left in the alveolar bone after molar extraction, which requires a longer healing time, thus allowing the sinus to pneumatize.

Pneumatization of the sinus after extractions can have various treatment-planning implications, such as reduction of the alveolar bone height available for implants[3] or complications in preprosthetic surgery (eg, tuberoplasty).[18]

Studies on maxillary sinus pneumatization have yielded conflicting results. Some have found an increase in sinus size after extractions, while others have found no change. Rosen and Sarnat[14] found a larger sinus volume in 7 of the 10 dogs in their study 6 to 12 months after extraction of all posterior maxillary teeth on 1 side of the jaw. Wehrbein and Diedrich[13] found pneumatization of the maxillary sinus by superpositioning transparent-paper tracings of panoramic radiographs before and after molar extraction and orthodontic space closure. Harorh and Bocutoglu[15] examined the width and height of maxillary sinuses on Waters' view radiographs of dentate and edentulous subjects and found a significantly greater average sinus height in the edentulous sample. Ohba et al[16] found the maxillary sinus floors of edentulous subjects to be inferiorly positioned compared with those of dentate subjects. Ariji et al[19,20] measured the volume of maxillary sinuses on axial computerized tomographic (CT) scans of adult subjects with and without posterior maxillary teeth and found no effect of the dentition status on the sinus size.

No clinical radiographic study in the literature has investigated changes in the position of the maxillary sinus floor in relation to fixed anatomic structures before and after tooth extraction in the same subject. The aim of this study was to identify and measure postextraction maxillary sinus pneumatization using fixed reference lines on panoramic radiographs.

MATERIALS AND METHODS

The panoramic radiographs in this retrospective study were selected from archived dental records of patients who completed dental treatment at the Department of Oral Rehabilitation, Chaim Sheba Medical Center, Tel-Hashomer, Israel. The protocol for the study was approved by the Committee for Research on Human Subjects, Israeli Defense Forces Medical Corps, Tel-Hashomer, Israel. The panoramic radiographs were all obtained with the same Orthoralix-S panoramic machine (Gendex Dental Systems, Milan, Italy) set at 74 kV and 10 mA, with a 12-second exposure time. The image receptor was a Kodak Lanex X-Omatik intensifying screen, and the x-ray film was developed with a Mini-Medical 90 automatic processing unit (AFP Imaging, Elmsford, NY).

All included radiographs were from subjects who were 19 years of age or older who had no history of nasal and sinus diseases, sinus surgery, or diseases affecting the bone. All clearly showed the roots of the posterior maxillary teeth, the maxillary sinus floor, the zygomatic processes, and the inferior orbital margins.

Three reference lines were marked with a pencil on all radiographs under standard conditions of illumination by 2 observers (AS, DM). The method used for evaluating vertical distances on panoramic radiographs was similar to those described by Packota et al[21] and Xie et al.[22] An interorbital line joining the most inferior points of both orbital margins and 2 zygomatic process lines, each passing through the most inferior margin of the zygomatic process on each side of the jaw parallel to the interorbital line (Fig 1), were drawn.

All radiographs were scanned and digitized with an Astra 3450 scanner (UMAX, Umax Technologies, Shanghai, China) and a personal computer using a resolution of 300 dpi. The images were aligned so that the interorbital line paralleled the framework of the screen, magnified by 200%, and measured with Adobe Photoshop 7.0 (San Jose, CA) to the nearest 0.1 mm by the same examiners. Panoramic images in which the interorbital line was tilted superoinferiorly by more than 5 degrees in relation to the horizontal frame of the radiograph were not included to avoid loss of accuracy.[22]

The measurements in this study included the distance between the interorbital line and the zygomatic process line and the distance between the interorbital line and the maxillary sinus floor superior to either the second premolar, first molar, or second molar, as these are the teeth whose roots are closest to the sinus.[23] The pencil lines marking the 3 reference lines were about 0.2 mm wide in the digital

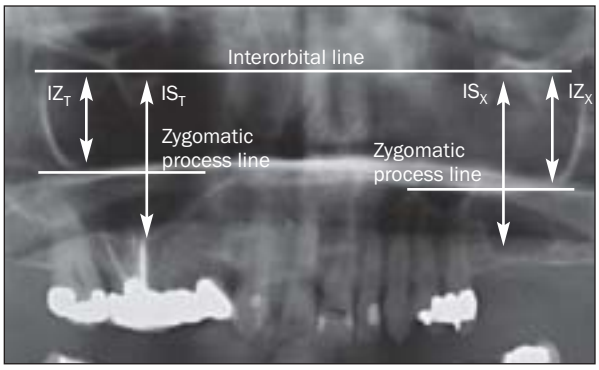


Fig 1 Panoramic image illustrating the reference lines drawn and the perpendicular distances measured in the study.

images. Measurements were therefore made from the center of each pencil line. Every measurement was made 3 times, and the mean of the 3 measurements was used for the statistical analysis. The average standard deviation between each 3 measurements was 0.13 mm. Intraexaminer variation was determined by repeating the marking of the reference lines and measurements on 40% of the radiographs, with an interval of 1 week separating the first and second measurements. No statistically significant difference was found between replicate measurements ($P = .19$; paired t test).

The study was designed with 2 parts, each with a control group and an experimental group. The first part evaluated sinus expansion via the comparison of dentate and contralateral edentulous sites. The second part evaluated sinus expansion by comparison of the same site before and after extraction.

Dentate Versus Edentulous Sites

Panoramic radiographs (n = 152) of 135 men and 17 women (average age, 40 years) were selected. Each subject was missing at least 1 posterior maxillary tooth (second premolar, first molar, or second molar) on 1 side of the jaw only but was fully dentate in the contralateral posterior maxilla. Only radiographs obtained at least 6 months after tooth loss were included in the study, and only if none of the cortical outline of the socket remained.

The vertical distances between the interorbital line and the inferior cortical border of the maxillary sinus (IS) in the area of the missing tooth and in the area of the contralateral existing tooth were measured. The lengths of the vertical distances between the interorbital line and the zygomatic process lines (IZ) on both sides of the jaw were also measured (Fig 1).

The position of the sinus floor was expressed as a ratio using the distance IS as a numerator and the distance IZ as a denominator. This ratio compensated for the distortion between the right and left sides of the same panoramic radiograph that occurs as a result of head tilting of the subject.[22,24]

The null hypothesis was that $IS_X/IZ_X = IS_T/IZ_T$, where X was the side of the missing tooth and T the side with the tooth present. The calculation $IS_X - (IS_T * IZ_X/IZ_T)$ was deduced from the null-hypothesis equation to give the superoinferior differences of the sinus floor position between the side of the missing tooth and the side of the existing tooth. A positive value indicated a more inferiorly located sinus floor on the side of the missing tooth.

Sixty-four panoramic radiographs (45 men and 19 women; average age, 28 years) with all posterior teeth on both sides of the maxilla served as a control group to measure differences of the sinus floor position between the right and left sides of the same subject in the area above either the second premolar, first molar, or second molar (chosen at random). Measurements were performed using the same method described for the experimental group.

Pre-extraction Versus Postextraction

Fifty-eight pairs of panoramic radiographs were selected. Each pair was obtained from the same subject (50 men and 8 women; average age, 41 years). The first radiograph in each pair was obtained when all posterior teeth on the examined side were present, and the second was obtained at least 6 months after the extraction of a second premolar, first molar, and/or second molar. The sinus floor position was measured in 72 maxillae with a follow-up time of 6 to 67 months.

In the first radiograph, the tooth to be extracted was classified according to the topographic relationship between its root and the maxillary sinus floor (Fig 2), as described in a previous study.[25] In cases of class 3 roots, the root projection on the sinus cavity was determined by measuring the length from the root apex to the superior part of the cortical inferior wall of the sinus along the longitudinal axis of the root. For each tooth, only the root with the highest classification and projection length was measured. The lengths of the vertical distances IS and IZ pertaining to the sinus floor above the tooth to be extracted were measured before and after extraction.

The aforementioned calculation was performed to find the superoinferior differences in the position of the sinus floor between the second (postextraction) and first (pre-extraction) radiographs; in this case, T was the site of the tooth to be extracted, and X was the postextraction site. The ratio IS/IZ compensated for the distortions between 2 panoramic radiographs of the same subject.[22,24]

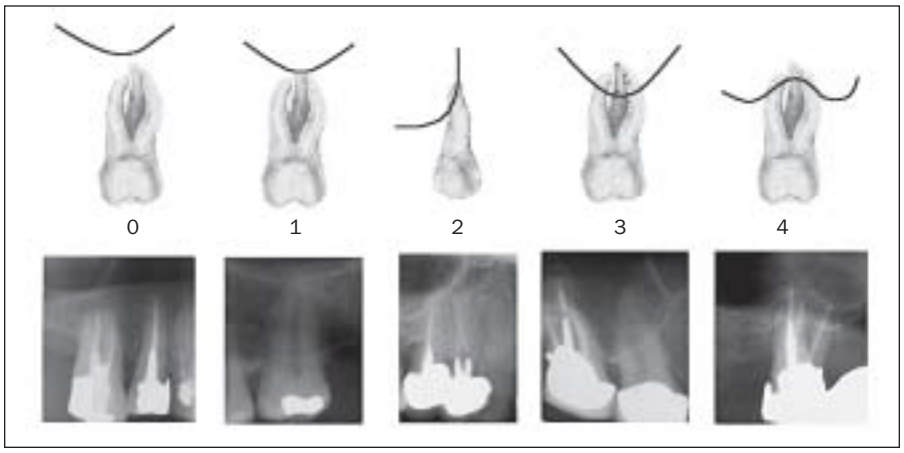


Fig 2 Schematic illustrations and panoramic images of the 5 classifications of maxillary posterior teeth roots in relation to the inferior wall of the sinus. *(0)* The root is not in contact with the cortical borders of the sinus; *(1)* an inferiorly-curving sinus floor, with the root in contact with the cortical borders of the sinus; *(2)* an inferiorly-curving sinus floor, with the root projecting laterally on the sinus cavity but with the root apex outside the sinus boundaries; *(3)* an inferiorly-curving sinus floor, with the root apex projecting on the sinus cavity; *(4)* a superiorly-curving sinus floor enveloping part or all of the tooth root. L = measurement of the root-projection length on the sinus cavity.

Forty-one pairs of panoramic radiographs served as a control group; each pair was obtained from the same subject (34 men and 7 women; average age, 37 years). All control subjects had all posterior teeth on both sides of the maxilla, and the second radiograph in each pair was obtained at least 6 months after the first. The lengths IS and IZ were measured in 62 maxillae to calculate the superoinferior differences of the sinus floor position between the first and second radiographs in the area superior to either the second premolar, first molar, or second molar (chosen at random).

Statistical Analysis

The statistical evaluation (SPSS, Chicago, IL) included calculation of means and standard deviations of all groups and 2-tailed *t* tests between the results of the control and experimental groups. In the comparison of dentate and edentulous sites, a possible statistical relation between sinus expansion and missing tooth type was tested by 1-way analysis of variance (ANOVA). In the comparison between pre-extraction and postextraction sites, possible statistical relationships between sinus expansion after extraction and the following variables were tested by correlation analyses (*t* tests and ANOVA): *(1)* classification and projection length of the tooth root before the extraction, *(2)* the type of tooth extracted, *(3)* the number of missing teeth adjacent to the extracted tooth, and *(4)* the time elapsed after extraction. In all analyses, a significance level of .05 was used. All subjects received the same weight in the statistical analysis according to the number of paired sites evaluated in their radiographs to study differences between subjects and not between individual teeth. Weighting of the results allowed all subjects to have the same influence on the statistical analysis.

RESULTS

Dentate Versus Edentulous Sites

In the control group, no significant differences were found between the right and left sides of fully dentate subjects (mean difference, 0.13 ± 1.49 mm; n = 64; $t = 0.7$; 2-tailed *t* test). Thus, the null hypothesis was accepted in subjects with full posterior dentition. In the control group, no correlation was found with respect to the type of tooth above which the sinus floor was measured ($P = .98$).

The results of the experimental group showed a more inferiorly located sinus floor on the side of the missing posterior tooth, with a mean difference of 2.18 ± 2.89 mm (n = 152). This difference was statistically significant in comparison to the difference found in the control group ($t = 6.82$, $P < .001$; 2-tailed *t* test).

A 1-way ANOVA (Tables 1a and 1b) indicated significant differences in the extent of inferior sinus expansion among missing tooth types. The largest expansion occurred when a second molar was missing (3.56 ± 4.06 mm), with a significant difference between second molar and first molar extractions (1.69 ± 2.43 mm; $P < .05$).

There were no significant differences between male and female subjects in either the control ($t = 1.66$, $P = .1$) or experimental group ($t = 0.11$, $P = .91$).

Table 1a ANOVA for Sinus Expansion According to the Type of Tooth Missing: Dentate Versus Edentulous Sites

	Sum of squares	df	Mean square	F	*P*
Between groups	86.48	2	43.24	5.48	.005
Within groups	1176.72	149	7.90		
Total	1263.20	151			

Table 1b ANOVA Results for Sinus Expansion According to the Type of Tooth Missing: Dentate Versus Edentulous Sites

		Inferior sinus expansion (mm)	
Type of missing tooth	No. of cases	Mean	SD
Second molar	32	3.56	4.06
Second premolar	18	2.46	2.00
First molar	102	1.69	2.43

Sinus expansion values not joined by vertical lines are significantly different from each other ($P < .05$).

Table 2a ANOVA for Sinus Expansion According to the Classification of the Extracted Tooth: Pre-extraction Versus Postextraction

	Sum of squares	df	Mean square	F	*P*
Between groups	216.8	2	108.4	46.62	.001
Within groups	127.87	55	2.33		
Total	344.67	57			

Table 2b ANOVA Results for Sinus Expansion According to the Classification of the Extracted Tooth: Pre-extraction Versus Postextraction

		Inferior sinus expansion (mm)	
Classification of tooth extracted	No. of cases	Mean	SD
0 to 2	21	0.58	1.07
3	24	0.90	1.80
4	14	5.27	1.59

Sinus expansion values not joined by vertical lines are significantly different from each other ($P < .05$).

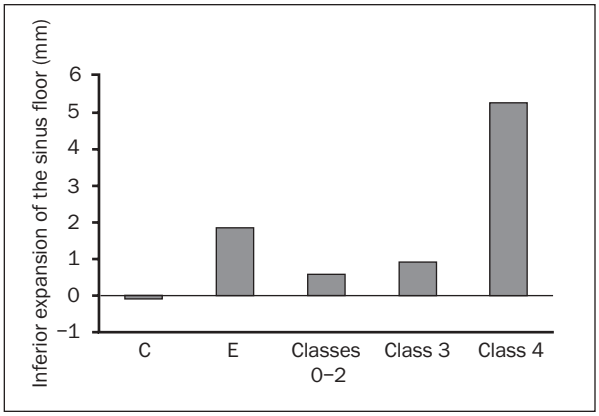


Fig 3 Inferior expansion of the sinus floor in postextraction versus pre-extraction sites, according to the classification of the extracted tooth. C = control group; E = experimental group.

Pre-extraction Versus Postextraction

The control group did not show significant differences of the sinus floor superoinferior position in pairs of panoramic radiographs of the same dentate posterior site (–0.10 ± 1.05 mm, n = 41, $t = 0.62$; 2-tailed *t* test). No correlation was found with the type of tooth above which the sinus floor was measured ($P = .22$) or the time elapsed between the first radiograph and the second ($P = .70$).

The results of the experimental group showed a more inferiorly located sinus floor on the postextraction radiograph, with a mean difference of 1.83 ± 2.46 mm (n = 58). This difference was statistically significant in comparison to the difference found in the control group ($t = 5.32$, $P < .001$; 2-tailed *t* test).

There were no significant differences between male and female subjects in either the control group ($t = 0.87$, $P = .41$) or the experimental group ($t = 0.6$, $P = .56$).

The results of the inferior sinus expansion were analyzed by a 1-way ANOVA (Tables 2a and 2b) in relation to the classification of the tooth before extraction; significant differences between the control and experimental groups were found. A considerable expansion was noted when the extracted tooth was of classification 4 (5.27±1.59 mm). It was significantly different from all other classifications ($P < .05$; Fig 3).

A 1-way ANOVA also indicated significant differences in sinus expansion among the type of teeth extracted (Tables 3a and 3b). As in the first experimental group, the largest expansion occurred following extractions of second molars (2.91 ± 2.61 mm).

The correlation between the amount of postextraction inferior expansion of the sinus and the root projection length of the extracted tooth on the sinus cavity was examined. No significant correlation was

Table 3a ANOVA for Sinus Expansion According to the Type of Tooth Extracted: Pre-extraction Versus Postextraction

	Sum of squares	df	Mean square	F	*P*
Between groups	44.8	2	22.4	4.11	.027
Within groups	299.87	55	5.45		
Total	344.67	57			

Table 3b ANOVA Results for Sinus Expansion According to the Type of Tooth Extracted: Pre-extraction Versus Postextraction

Type of extracted tooth	No. of cases	Inferior sinus expansion (mm) Mean	SD
Second molar	23	2.91	2.61
Second premolar	5	0.98	0.98
First molar	29	1.14	2.27

Sinus expansion values not joined by vertical lines are significantly different from each other ($P < .05$)

found (correlation coefficient = –0.23, n = 24, $P = .28$). The correlation between the amount of postextraction inferior expansion of the sinus and the period between the pre-extraction and postextraction radiographs (beyond the minimal 6 months required for socket healing) was also examined. No significant correlation was found (correlation coefficient = 0.118, n = 51, $P = 20$).

In cases in which 2 or more adjacent posterior teeth were extracted in the same site, a 2-tailed *t* test ($t = 2.81$, $P < .01$) showed a significantly larger sinus expansion (2.22 ± 2.54 mm, n = 45) in comparison with cases in which only 1 tooth was extracted and all the adjacent teeth remained (0.54 ± 1.70 mm, n = 14).

A qualitative analysis of the sinus floor topography in postextraction radiographs of teeth that were classified as 3 or 4 before the extraction showed that in 94% of the cases the sinus floor appeared flat or inferiorly curving after the completion of socket healing and that convexities and prominences in the sinus floor remained in only 6% of the cases.

DISCUSSION

The results of this study suggest that maxillary sinus pneumatization may occur after posterior tooth extraction.

The phenomenon of pneumatization has been investigated by only a few previous clinical studies,[13,15,16,19,20] each having various shortcomings:

1. Failure to use 2 fixed reference lines. The method of marking reference lines using fixed anatomic landmarks on panoramic images allows compensation for the distortion between right and left sides of the same radiograph or between 2 different radiographs of the same subject that can occur as a result of head tilting.[22,24]
2. Lack of consideration for different sinus sizes between subjects. Most studies have compared results of sinus measurements in a pool of subjects rather than in the same subject only. This can lead to reduced accuracy, since sinus sizes between subjects can differ by up to 25%.[21]

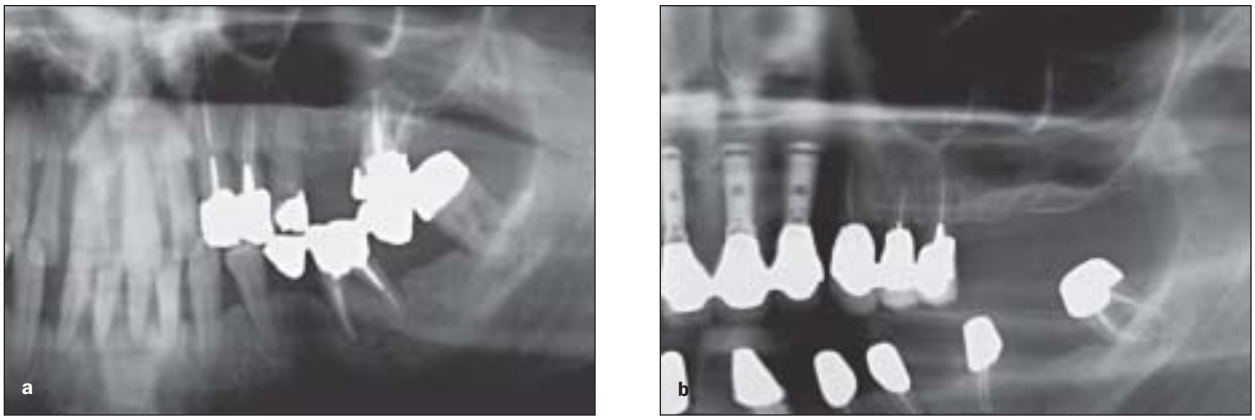
In the present study, panoramic radiography was used to measure sinus floor position changes in areas of missing teeth in the same subject only. The reference lines described by Packota et al[21] to evaluate vertical distances on panoramic radiographs were used. These lines lie in the same vertical plane as the maxillary sinus floor and the posterior teeth roots, thus allowing for accurate measurement.[24] Only vertical measurements were used, as the vertical magnification in panoramic radiography is relatively uniform.[26–28]

An inferior expansion of the maxillary sinus floor in sites of extracted teeth (1.83 to 2.18 mm) was observed both when comparing an edentulous site to its contralateral dentate site and when comparing the same site before and after extraction. The inferior expansion of the sinus floor is hypothesized to be caused by active sinus pneumatization after tooth extraction.

Evaluation of the influence of extraction of different tooth types indicates a larger sinus pneumatization after loss of a second molar (2.91 to 3.56 mm). Previous clinical studies have indicated that the closest proximity between the sinus floor and the teeth is found in the second molar area.[23,29,30] As a result of this proximity, extractions may cause a frequent loss of the thin bone separating the alveolar socket from the sinus, thus allowing the sinus to expand.

Analysis of the results according to the topographic relation between the tooth and the sinus floor indicates a considerably larger pneumatization following the extraction of teeth surrounded by a

Figs 4a and 4b Panoramic radiographs of the same subject *(left)* before and *(right)* 6 months after the extraction of the right second molar demonstrating an inferior expansion of the sinus floor and a change in its topography from superiorly curving to flat.



Figs 5a and 5b Panoramic radiographs of the same subject *(left)* before and *(right)* 53 months after extraction of the left second molar demonstrating an inferior expansion of the sinus floor and a change in its topography from superiorly curving to flat.

superiorly curving sinus floor (classification 4). This topography, according to Waite,[31] occurs when the sinus extends between adjacent teeth, creating elevations in the antral surface. It also occurs at sites of dental periapical lesions, which naturally elevate the sinus membrane.[32] Examination of the postextraction topography of the sinus floor showed that in most cases the superiorly curving sinus floor became flat or inferiorly curving as a result of sinus expansion (Figs 4 and 5). This may explain the significant pneumatization found in these cases (5.27 ± 1.59 mm).

The projection of tooth roots into the sinus cavity was not found to be statistically correlated with sinus pneumatization after extraction, in contrary to the results of Wehrbein and Diedrich.[13] The lack of correlation in the present study may be explained by the results of a previous study[25] indicating that the majority of roots that project into the sinus cavity in panoramic radiographs (58.5%) do not truly protrude into it (as can be seen in CT images of the same teeth). Therefore, root projection into the sinus cavity in panoramic radiographs may not necessarily have pneumatization consequences after dental extractions, depending on the true topographic relation between the tooth and the sinus.

The time elapsed after tooth extraction beyond the minimal 6 months necessary for the healing of the socket was not found to be correlated with sinus pneumatization. This indicates that postextraction pneumatization occurs within the socket healing period of 4 to 6 months.[3] After mature bone has developed in the extraction socket, the pneumatization process is probably reduced to a minimum or ceases entirely.

A larger sinus expansion was found in cases of extractions of more than 1 tooth in the same area (2.22 ± 2.54 mm, n = 45). This may be expected because of the reduced bone resistance to sinus pneumatization in cases of several extraction sockets adjoining one another. In cases in which only 1 tooth

is extracted, the roots of the neighboring teeth probably prevent the sinus from expanding by transferring functional forces to the area of the missing tooth. Negligible expansion of the sinus floor has been found in these cases (0.54 ± 1.70 mm, n = 14).

In summary, the clinician extracting a maxillary posterior tooth should be aware of the increased probability for sinus pneumatization in the following cases:

1. Teeth surrounded by a superiorly curving sinus floor
2. Tooth roots shown to protrude into the sinus cavity by CT imaging
3. Extraction of second molars
4. Extractions of several adjacent posterior teeth or extraction of a tooth with missing adjacent teeth

If dental implant placement is planned in these cases, the clinician should consider preserving as much bone height as possible by immediate implantation and/or by immediate bone grafting at the time of extraction.[33,34] These procedures might help maintain the 3-dimensional architecture of the thin sinus floor in the extraction site[35] until complete healing of the socket, thus preventing or decreasing pneumatization. Further study is suggested to examine the effect of socket grafting on the pneumatization of the sinus.

CONCLUSIONS

Within the limitations of this retrospective study, the following conclusions were reached:

1. Sinus pneumatization was identified after the extraction of maxillary posterior teeth.
2. Sinus expansion was considerably larger in cases of extractions of teeth enveloped by a superiorly curving sinus floor. In most of these cases, the sinus floor topography changed to flat or inferiorly curving after extraction socket healing.
3. Sinus expansion was larger in cases of second molar extractions (in comparison to first molars) and in cases of extraction of 2 or more adjacent posterior teeth.

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Erratum

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