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Factors affecting maxillary sinus pneumatization following posterior maxillary tooth extraction

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ABSTRACT

Purpose: The aims of the present study were 1) to quantitatively evaluate the extent of sinus pneumatization and 2) to determine the factors affecting sinus pneumatization.
Methods: Based on implant treatment records, a list of patients who underwent implant placement on the posterior maxilla was obtained. Among them, patients with pre-extraction and post-extraction (before implant placement) panoramic radiographs were selected. After excluding radiographs with low resolution and image distortion, the radiographs before and after extraction were superimposed using computer software. Subsequently, the extent of sinus pneumatization (the vertical change of the sinus floor) was measured. Simple and multiple mixed models were used to determine the factors affecting sinus pneumatization.
Results: A total of 145 patients were eligible for the present investigation. The average extent of sinus pneumatization was 1.56±3.93 mm at 176 tooth sites. Male sex, single tooth extraction, extraction of an endodontically compromised tooth, a class I root-sinus relationship, and sinus membrane thickening >10 mm favored pneumatization, but without statistical significance. The maxillary second molar presented the greatest pneumatization (2.25±4.39 mm) compared with other tooth types. This finding was confirmed in the multiple mixed model, which demonstrated a statistically significant impact of the extraction of a second molar compared with the extraction of a first premolar.
Conclusions: Maxillary sinus pneumatization was 1.56±3.93 mm on average. The extraction of a second molar led to the greatest extent of pneumatization, which should be considered in the treatment plan for this tooth site.

Keywords: Bone resorption; Maxillary sinus; Radiography

INTRODUCTION

The main concern regarding implant treatment in the posterior maxilla is the presence of the maxillary sinus [1]. The varying extension of the sinus toward the coronal direction may limit the bone height for placing implants of an adequate length. Depending on the available bone height, the extent of surgical invasiveness can be determined.

Author Contributions
Conceptualization: Hyun-Chang Lim, Seung-Il Shin; Formal analysis: Sangyup Kim, Do-Hyup Kim; Investigation: Hyun-Chang Lim, Sangyup Kim, Do-Hyup Kim; Methodology: Jong-Hyuk Chung, Yeek Herr; Project administration: Hyun-Chang Lim, Sangyup Kim, Do-Hyup Kim; Writing - original draft: Sangyup Kim; Writing - review & editing: Hyun-Chang Lim, Seung-Il Shin, Jong-Hyuk Chung, Yeek Herr.

Conflict of Interest
No potential conflict of interest relevant to this article was reported.

Previous studies have demonstrated physiologic and post-physiologic changes of the maxillary sinus. Physiologically, the maxillary sinus is continuously pneumatized after birth. One study demonstrated that this process lasted until the second decade in females and until the third decade in males [2]. In another study, the greatest pneumatization was noted between the ages of 19 and 30 [3]. The cause and extent of sinus pneumatization remain unclear, but the following reasons are suspected: heredity, craniofacial configuration, bone density, growth hormones, and air pressure in the sinus cavity [3-5].

Post-physiologically, posterior tooth extraction in the maxilla may provoke alveolar ridge remodeling involving an increase in the size of the maxillary sinus. Clinically, maxillary sinus pneumatization (MSP) can lessen the available bone height for future implant placement, together with ridge resorption in the coronal portion of the extraction socket [6,7]. MSP is sometimes thought to be part of disuse atrophy, which involves a reduction in the mechanical strength of the bone tissue adjacent to the extraction site [7,8].

Several studies have investigated the amount and causal factors of pneumatization after tooth extraction, reporting to conflicting results. Some demonstrated an increase in the size of the sinus after tooth extraction [6-11], while others did not find significant changes [12-14]. Moreover, among the studies reporting MSP post-extraction, heterogeneity has been reported regarding conditions that favor susceptibility and the extent of pneumatization. The reported conditions were tooth location, the configuration of the sinus floor, the position of the sinus floor concerning the root apex, and the number of extracted teeth [8,13]. The extent of pneumatization ranged considerably, with reported values of 0.47±0.23 mm (mean ± standard deviation [SD]) [13], 0.9±2.93 mm [9], 2.18±2.89 and 1.83±2.46 mm [8], and 1.30±0.27 mm (mean ± SE) [7]. Due to the above conflicting results and heterogeneity, the sequelae of posterior tooth extraction in the maxilla require further investigation.

The present study aimed to measure the extent of MSP following tooth extraction and to determine the factors affecting MSP through a comparison of pre-extraction and post-extraction panoramic radiographs.

MATERIALS AND METHODS

Study design

The study protocol of the present study was approved by the Institutional Review Board of Kyung Hee University Dental Hospital, Seoul, South Korea (KH-DT19039). To obtain panoramic radiographs taken before extraction and after healing, we used the dental implant surgery records of the Department of Periodontology of Kyung Hee University Dental Hospital. The implant placement procedures were performed between January 1, 2012 and September 30, 2018.

The following data were collected for eligible patients: First, all patients undergoing implant surgery in the posterior maxilla (between the first premolar and second molar) were identified. Next, the panoramic radiograph before implant surgery (T_h) was required to be present. When this radiograph was present, the patient's record was reviewed for the extraction of 1 or more teeth. Subsequently, the availability of a panoramic radiograph taken before extraction (T_e) was identified.

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Inclusion and exclusion criteria

The following inclusion criteria were used: 1) age over 20 years old, 2) the presence of panoramic radiographs at T_e and T_h, and 3) an interval of less than 3 months between the date of panoramic radiography at T_e and the date of extraction. The exclusion criteria were as follows: 1) panoramic radiographs with low resolution and image distortion and 2) panoramic radiographs in which it was difficult to discern the outline of the maxillary sinus.

Selection of the radiographs

Initially, 404 patients were identified based on the implant records. These patients were traced back. Subsequently, the interval between the date of the panoramic radiographs taken before extraction and the date of extraction was calculated. Patients with an interval between the 2 dates of <3 months were selected, leaving a sample of 198 patients. Subsequently, panoramic images with low resolution and high distortion were discarded. Finally, panoramic images from 145 patients (87 men and 58 women) with 176 teeth sites remained for analysis (Figure 1).

Data collection and measurements

Through chart review, we collected data, including age, sex, tooth site, the number of extracted teeth, the reason for extraction, and the time between the extraction and T_h (≤6 months or >6 months and ≤12 months or >12 months).

On the pre-extraction panoramic radiographs, the following measurements were made: i) the relationship between the root and the sinus floor, as suggested by Sharan and Madjar [8] (class I: the root not in contact with the lower border of the sinus, class II: the root in contact with the lower curved border of the sinus floor, class III: the root positioned laterally outside of the mesial border of the sinus, class IV: the root protruding to the lower curved border of the sinus floor, class V: the root bordered by the upper curved border of the sinus floor), and ii) the extent of sinus membrane thickening (SMT) (SMT <5 mm, 5 mm ≤ SMT < 10 mm, SMT ≥10 mm) (Figure 2).

For superimposition, the matching panoramic radiographic images before and after extraction were imported to PowerPoint (Microsoft Corp., Redmond, WA, USA). Teeth or implants adjacent to the extraction site(s) and zygomatic processes were used as references [7,8]. Two matching images were superimposed using the tool for resizing/rotating the

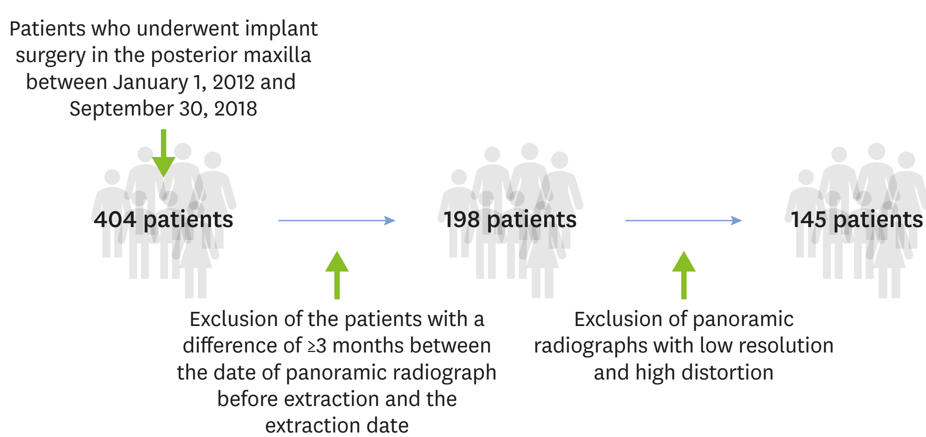

Figure 1. Diagram of selection of the patients.

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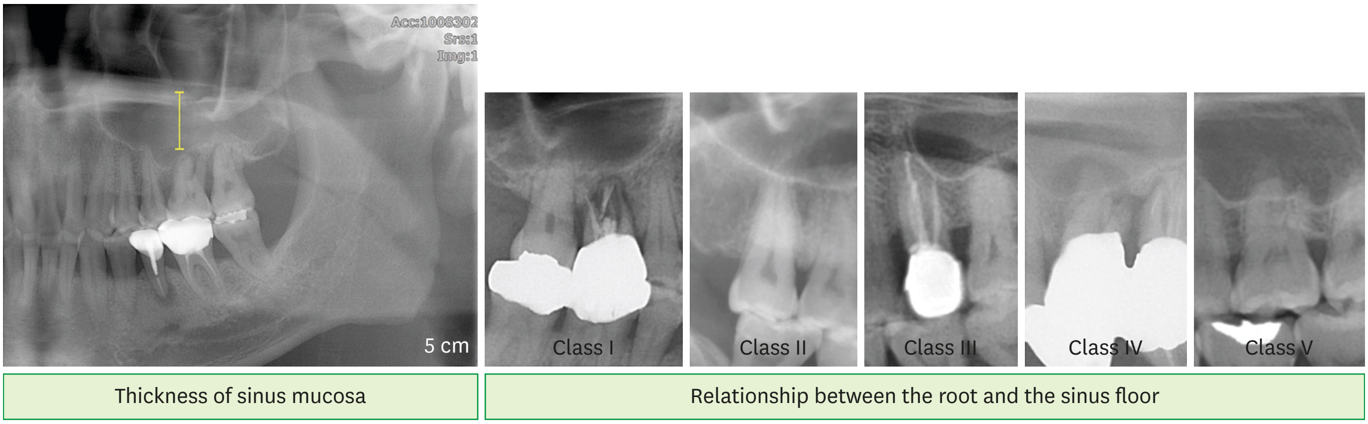

Figure 2. Radiologic measurement of sinus membrane thickening (left) and the relationship between the root and the sinus floor (right). The bar indicates the extent of sinus membrane thickening. Class I: the root not in contact with the lower border of the sinus, class II: the root in contact with the lower curved border of the sinus floor, class III: the root positioned laterally outside of the mesial border of the sinus, class IV: the root protruding to the lower curved border of the sinus floor, class V: the root bordered by the upper curved border of the sinus floor.

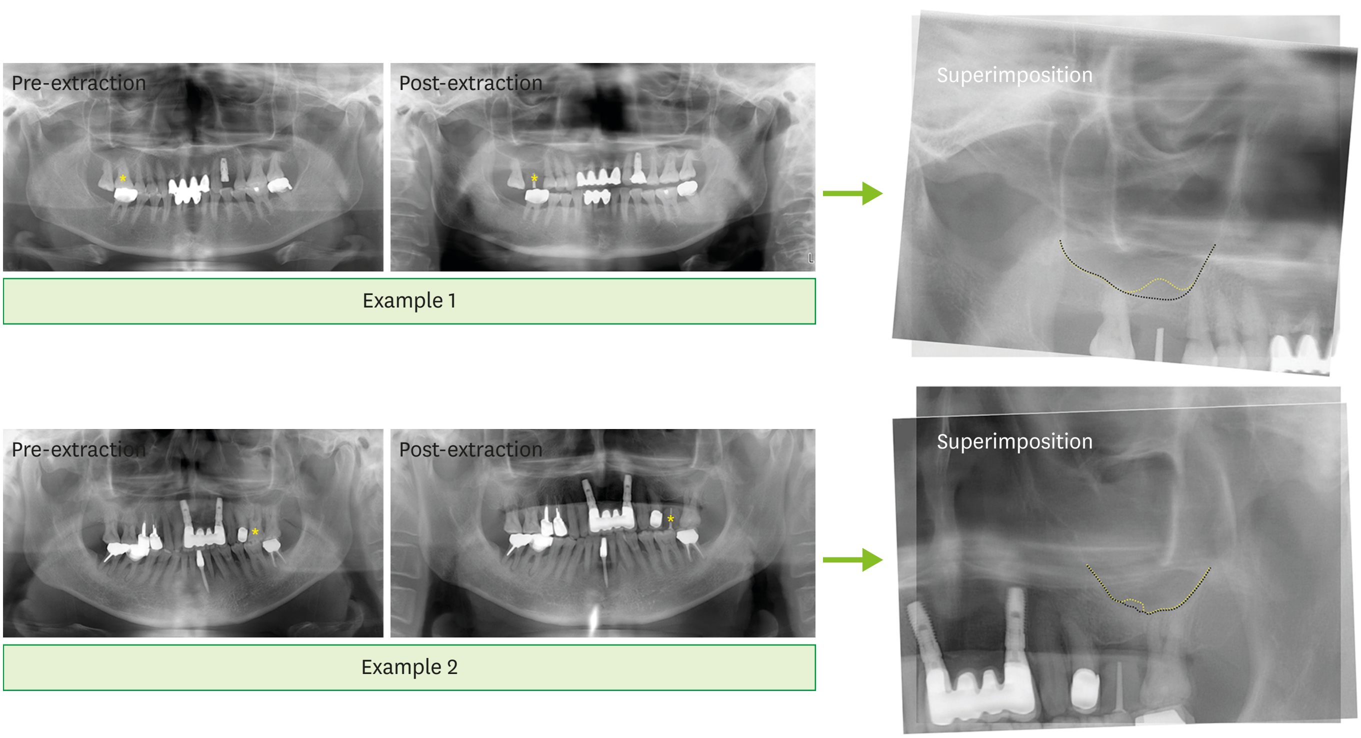

Figure 3. Examples of superimposition. The matching panoramic radiographic images before and after extraction were imported into computer software. Teeth/implants adjacent to the extraction site(s) and zygomatic processes were used as references. With the use of the tool provided by the software, 2 matching images were superimposed.

images and modifying the opacity/transparency of the images. The change in the distance between the bone crest and the border of the sinus floor was then measured. For this measurement, we used the length of the existing adjacent tooth/implant measured with a tool provided in the radiographic image viewer program (ZeTTA PACS viewer, TAEYOUNG SOFT, Anyang, Korea) (Figure 3).

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Inter-examiner calibration

Radiographic measurements were performed by 2 authors of the present study (S.K. and D.H.K.). Prior to the measurements, the procedure was performed by a senior investigator (H.C.L.). Ten random samples were then used for calibration. Inter-examiner reproducibility was assessed using intraclass correlation coefficients, resulting in 0.837 (P<0.05).

Statistical analyses

Data were analyzed using commercially available statistical software (SAS version 9.4; SAS Institute, Cary, NC, USA). Numerical data are presented as mean ± SD, median, and interquartile range. Due to the inclusion of more than 1 tooth site in some patients and the presence of multiple independent variables, simple and multiple mixed models for linear regression were used to identify statistically significant factors (sex, age, single/multiple extraction, cause of extraction, relationship between the root and the sinus floor, and SMT) for MSP. The level of statistical significance was set at P<0.05.

RESULTS

Included teeth

Among the 176 teeth that were included, there were 21 first premolars, 34 second premolars, 89 first molars, and 32 second molars. Single and multiple extractions were performed for 98 and 78 teeth, respectively (extraction of 2 teeth in 66 cases and 3 teeth in 12 cases). The predominant cause of extraction was periodontal problems (n=141), followed by fracture (n=17), endodontic problems (n=9), and unknown (n=9). The relationship between the root and the sinus floor was classified as class I (n=73), class II (n=51), class III (n=27), class IV (n=12), and class V (n=12). The extent of SMT was as follows: SMT <5 mm (n=130), 5 mm ≤ SMT < 10 mm (n=34), and SMT ≥10 mm (n=12) (Table 1).

Amount of pneumatization and regression analysis

In all included teeth

The mean value of MSP was 1.56±3.93 mm. Women had more sinus expansion than men. Single tooth extraction presented a greater amount of MSP (2.09±3.11 mm) than multiple tooth extraction (0.89±4.71 mm). Among the tooth types, second molars exhibited the greatest extent of MSP (2.25±4.39 mm), followed by first molars (1.90±4.02 mm), second premolars (0.78±3.07 mm), and first premolars (0.34±3.88 mm). Of the various reasons for extraction, the greatest degree of sinus expansion was shown after extraction procedures performed due to endodontic problems (2.28±2.37 mm). Regarding the classification of the relationship between the root and the sinus floor, the greatest amount of MSP occurred in class I (2.12±3.95 mm), followed by class IV, class II, class V, and class III (0.55±3.96 mm). When the SMT pre-extraction was higher than 10 mm, the greatest amount of MSP occurred (2.84±5.74 mm). The time interval following tooth extraction was not proportional to the amount of MSP.

In the simple mixed model, none of the parameters demonstrated statistical significance. In the multiple mixed model, second molars exhibited a statistically significant influence on MSP compared with first premolars (estimate: −2.35 mm, P=0.0177). An “unknown” reason for extraction showed statistical significance compared with “periodontally compromised” (estimate: 3.1 mm, P=0.014) (Table 2).

Table 1. Details of the included teeth

Variables	All teeth	Teeth with a vertical height of the alveolar bone <10 mm
Sex		
Male (n=105)	−1.36±4.01	−0.66±3.99
Female (n=71)	−1.86±3.82	−1.39±3.91
Number of extracted teeth		
Single extraction (n=98)	−2.09±3.11	−1.67±2.99
Multiple extraction (n=78)	−0.89±4.17	−0.13±4.73
Tooth site		
First premolar (n=21)	−0.34±3.88	1.53±3.67
Second premolar (n=34)	−0.78±3.07	−0.58±3.19
First molar (n=89)	−1.9±4.02	−1.28±3.98
Second molar (n=32)	−2.25±4.39	−1.81±4.46
Reason for extraction		
Periodontal (n=141)	−1.79±3.56	−1.15±3.51
Endodontic (n=9)	−2.28±2.37	−2.28±2.37
Fracture (n=17)	−0.78±4.73	−0.20±4.76
Unknown (n=9)	1.2±7.39	2.22±8.10
Time interval following tooth extraction		
≤6 months (n=90)	−1.91±3.77	−1.28±3.74
>6 and ≤12 months (n=51)	−1.04±3.66	−0.23±3.40
>12 months (n=35)	−1.41±4.69	−1.15±5.01
Relationship between the root and the sinus floor		
Class I (n=73)	−2.12±3.95	−0.81±3.78
Class II (n=51)	−1.49±3.66	−1.39±3.8
Class III (n=27)	−0.55±3.96	−0.17±4.18
Class IV (n=12)	−1.5±3.35	−1.5±3.35
Class V (n=12)	−0.8±5.46	−0.8±5.46
Sinus mucosal thickening		
≤5 mm (n=130)	−1.43±3.32	−0.79±3.15
>5 and ≤10 mm (n=34)	−1.61±5.24	−1.11±5.62
>10 mm (n=12)	−2.84±5.74	−2.08±5.35

In teeth with vertical height of the alveolar bone <10 mm

The vertical height of the alveolar bone was measured on the distal and mesial surfaces of the teeth. Teeth with a height <10 mm on at least 1 proximal surface of the teeth were then selected. In these teeth (n=136), the mean amount of MSP was 0.96±3.96 mm. These teeth showed a tendency for greater MSP to occur in cases of single tooth extraction, extraction of the second molar, and SMT >10 mm, which is in line with the results for all included teeth. However, when the vertical height of the alveolar bone was <10 mm, the greatest amount of MSP occurred at sites with a class IV root-sinus floor relationship (1.5±3.35 mm), followed by class II, class I, class V, and class III (0.17±4.18 mm).

Similar to the mixed model analysis of all included teeth, the simple mixed model demonstrated no statistical significance for any variables. In the multiple mixed model, second molars also significantly influenced MSP compared with first premolars (estimate: −2.31 mm, P=0.0181) (Table 3).

DISCUSSION

The present study investigated the extent of MSP and determined the factors affecting MSP using panoramic radiographs. The results showed that 1) the extent of MSP following tooth extraction was 1.56±3.93 mm at all included tooth sites and 0.96±3.96 mm at tooth sites with a

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Table 2. Simple and multiple mixed model analyses in all teeth

Variables	Simple mixed model			Multiple mixed model		
	B estimate	Confidence interval	*P* value	B estimate	Confidence interval	*P* value
Sex						
Male (ref.)	0	-	-	0	-	-
Female	−0.45	−1.73, 0.83	0.4776	−0.59	−1.71, 0.54	0.2919
Age	−0.04	−0.1, 0.02	0.1504	0	−0.06, 0.05	0.8565
Number of extracted teeth						
Single extraction (ref.)	0	-	-	0	-	-
Multiple extraction	1.01	−0.29, 2.31	0.1233	0.89	−0.28, 2.05	0.1276
Tooth site						
First premolar (ref.)	0	-	-	0	-	-
Second premolar	−0.27	−2.08, 1.54	0.7615	−1.3	−3.02, 0.42	0.1317
First molar	−0.84	−2.49, 0.81	0.3052	−1.17	−2.97, 0.63	0.1897
Second molar	−1.29	−3.23, 0.65	0.1834	−2.35	−4.24, −0.45	0.0177
Reason for extraction						
Periodontal (ref.)	0	-	-	0	-	-
Endodontic	−0.6	−3.24, 2.04	0.6453	−0.83	−3.21, 1.55	0.4775
Fracture	0.67	−1.3, 2.64	0.4932	0.8	−0.99, 2.59	0.3652
Unknown	1.92	−0.84, 4.68	0.1653	3.10	0.7, 5.5	0.0140
Time interval following tooth extraction						
≤6 months (ref.)	0	-	-	0	-	-
>6 and ≤12 months	1.23	−0.22, 2.68	0.0939	1.02	−0.26, 2.3	0.1110
>12 months	0.48	−1.15, 2.12	0.5508	−0.04	−1.46, 1.38	0.9588
Relationship between root and sinus floor						
Class I (ref.)	0	-	-	0	-	-
Class II	0.74	−0.56, 2.04	0.2526	−1.06	−2.42, 0.3	0.1198
Class III	1.01	−0.55, 2.57	0.1964	−0.69	−2.27, 0.88	0.3704
Class IV	0.38	−1.89, 2.66	0.7313	−1.23	−3.43, 0.97	0.2588
Class V	0.39	−1.8, 2.57	0.7191	−1.55	−3.77, 0.67	0.1603
Sinus mucosal thickening						
≤5 mm (ref.)	0	-	-	0	-	-
>5 and ≤10 mm	−0.47	−2.05, 1.12	0.5540	−0.45	−1.9, 1.0	0.5250
>10 mm	−2.01	−4.58, 0.56	0.1208	−2.07	−4.3, 0.16	0.0673

vertical alveolar bone height of <10 mm, and 2) only extraction of the second maxillary molar significantly affected MSP among the various factors included in the multiple mixed model.

Several previous studies investigated the phenomenon of MSP using different models/methodologies. The subjects were sometimes animals [15], but mainly humans [6-8,10,13]. The applied tools for MSP were generally radiographic images: both 2-dimensional panoramic radiographs [7,8] and 3-dimensional computed tomography [6,13] were used. Furthermore, some studies compared the edentulous and dentate sides in the same individual [6,8], while others compared pre-and post-extraction measurements [8,10]. The majority of the studies showed some extent of MSP, but heterogeneity was noted in terms of the clinical significance of MSP.

In the present study, the mean extent of MSP was 1.56±3.93 mm on panoramic radiographs. This value aligns with those reported in other studies using panoramic radiographs: 1.3±0.27 mm in the study by Levi et al. [7] and 1.83±2.46 mm to 2.18±2.89 mm in the study by Sharan and Madjar [8]. In the studies using cone-beam computed tomography (CBCT), the extent of MSP seems to be inconsistent (between 0.8 mm and 2.5 mm [6], 1.16 mm [10], and less than 0.5 mm [13]). CBCT generally provides more accuracy and precision than panoramic radiography. Reports in the literature have shown image distortion on panoramic radiographs (e.g., a discrepancy between left and right sides, or different head positions in

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Table 3. Simple and multiple mixed model analyses in teeth with a vertical height of the alveolar bone <10 mm

Variables	Simple mixed model			Multiple mixed model		
	B estimate	Confidence interval	*P* value	B estimate	Confidence interval	*P* value
Sex						
Male (ref.)	0	-	-	0	-	-
Female	−0.77	−2.25, 0.7	0.2904	−0.64	−2.02, 0.74	0.3372
Age	−0.04	−0.03, 0.1	0.3427	0	−0.07, 0.06	0.8795
Number of extracted teeth						
Single extraction (ref.)	0	-	-	0	-	-
Multiple extraction	1.26	−0.21, 2.73	0.0898	1.09	−0.29, 2.48	0.1137
Tooth site						
First premolar (ref.)	0	-	-	0	-	-
Second premolar	−1.23	−3.44, 0.99	0.2621	−1.63	−3.73, 0.47	0.1184
First molar	−1.49	−3.59, 0.62	0.1567	−1.24	−3.6, 1.12	0.2799
Second molar	−2.31	−4.73, 0.11	0.0600	−2.98	−5.37, −0.59	0.0181
Reason for extraction						
Periodontal (ref.)	0	-	-	0	-	-
Endodontic	−1.13	−3.97, 1.7	0.4168	−0.29	−2.95, 2.37	0.8184
Fracture	0.35	−2.11, 2.8	0.7734	0.28	−2.02, 2.58	0.7974
Unknown	2.11	−1.12, 5.34	0.1893	4.26	1.27, 7.25	0.0084
Time interval following tooth extraction						
≤6 months (ref.)	0	-	-	0	-	-
>6 and ≤12 months	1.28	−0.41, 2.97	0.1310	0.9	−0.64, 2.43	0.2328
>12 months	0.01	−1.85, 1.87	0.9898	−0.54	−2.12, 1.13	0.5006
Relationship between the root and the sinus floor						
Class I (ref.)	0	-	-	0	-	-
Class II	−0.13	−1.71, 1.45	0.8633	−1.25	−2.86, 0.36	0.1196
Class III	0.29	−1.59, 2.17	0.7528	−0.94	−2.78, 0.89	0.2911
Class IV	−0.56	−3.02, 1.9	0.6403	−1.51	−3.95, 0.92	0.2054
Class V	−0.4	−2.76, 1.96	0.7268	−1.91	−4.36, 0.54	0.1169
Sinus mucosal thickening						
≤5 mm (ref.)	0	-	-	0	-	-
>5 and ≤10 mm	−0.79	−2.58, 1.00	0.3719	−0.55	−2.22, 1.12	0.4903
>10 mm	−1.73	−4.52, 1.07	0.2146	−1.81	−4.31, 0.06	0.8795

images taken at different time points) [6,8,16]. However, panoramic radiographs appeared to serve well for vertical measurements since the vertical magnification is relatively uniform [17,18]. In the present study, only vertical measurements were utilized to compensate for the limitations of panoramic radiography.

In the present study, a subgroup analysis was performed of tooth sites with a pre-extraction vertical alveolar bone height of <10 mm, based on a threshold used for short or standard implants [19,20]. If alveolar bone with initially short vertical height undergoes more pronounced MSP following tooth extraction, clinicians should expect to perform implant surgery with advanced techniques. However, in the present study, short alveolar ridges did not show greater MSP (0.96±3.96 mm), indicating that the effect of the initial alveolar bone height may be neglected, at least in terms of the extent of MSP.

Several factors were investigated in the present study. The influence of these factors was somewhat heterogeneous compared to other studies. In the present study, single tooth extraction was associated with a greater degree of apical expansion of the sinus floor than was observed after multiple extractions (2.09±3.11 mm vs. 0.89±4.71 mm), but in the studies by Sharan and Madjar [8] and Jung et al. [21], a greater amount of MSP was observed in cases of multiple extractions (0.54±1.7 mm vs. 2.22±2.54 mm and 1.11±1.81 mm vs. 2.14±2.47 mm, respectively). The authors explained that the root of the adjacent teeth might have a protective effect against MSP. In another study, only single-tooth extractions were included [13], and still other studies did not investigate the influence of single or multiple extractions because of the characteristics of the studies (comparing non-grafted sockets to sockets with alveolar ridge preservation in the posterior maxilla) [7,10].

A contradictory finding was also noted in terms of the relationship between the sinus floor and the root apex proposed by Sharan and Madjar [8]. When all included teeth were analyzed, class I presented the greatest amount of MSP. In teeth with a vertical height of alveolar bone < 10 mm, class IV demonstrated the greatest amount of MSP. However, Sharan and Madjar [8] reported the greatest amount of MSP when the root of the maxillary tooth was surrounded by the upper curved border of the sinus floor (class V). In the study by Jung et al. [21], the relationship between the sinus floor and the root apex had no significant impact on the extent of MSP. These discrepancies might be due to the difficulty in establishing the sinus floor on panoramic images, such as the difference in the position of the root apex on the buccal/palatal sides and furcal area.

The present study demonstrated greater MSP following tooth extraction in cases with SMT >10 mm (2.84±5.74 mm). This finding may be due to an inflammatory reaction on the sinus floor and alveolar bone, considering that most of the teeth with SMT >10 mm were endodontically compromised despite the small number of cases. Among the reasons for extraction, endodontically compromised teeth showed the greatest amount of MSP (2.28±2.37 mm). In a recent systematic review and meta-analysis, 1,550 maxillary sinuses related to peri-apical lesions were analyzed, demonstrating that the presence of periapical lesions was associated with up to a 2.43-fold greater risk of SMT >2 mm [22]. A study showed that a periapical lesion next to the maxillary sinus might be an origin of the spread of odontogenic bacteria, provoking SMT [23]. In particular, when the alveolar bone apical to the root apex is thin, extraction of a tooth with an apical lesion and severe SMT may exacerbate the resorption of the adjacent bone concomitantly with bundle bone resorption. In contrast, in the study by Hammed et al., SMT did not affect MSP, but they did not present the extent of SMT or the reason for extraction [13].

In the multiple mixed model, it is notable that extraction of the second molar showed a statistically significant relationship with MSP. This area is characterized by poor bone density and proximity to the sinus floor [24-26]. These traits may facilitate MSP in the second molar area compared to other areas [8,21]. The second molar area may be the most difficult for obtaining access and visibility due to its most distal location. Therefore, it might be beneficial to establish a plan to compensate for MSP in this area before extraction. One option to do so may be alveolar ridge preservation (ARP). A few studies favoring ARP in the posterior maxilla have been published [7,10,11]. In the study by Levi et al. [7], the change of the sinus floor in the sockets with or without ARP was −0.30±0.10 mm and −1.30±0.27 mm, respectively. The study by Cha et al. [10] also favored ARP, with a sinus floor level change of −1.16 mm in sockets without ARP and −0.14 mm in sockets with ARP. This positive effect of ARP may increase the feasibility of implant surgery for the second molar area [11].

The time interval between pre-extraction and post-extraction was divided into 1) ≤6 months, 2) >6 months and ≤12 months, and 3) >12 months. No association was found between the time interval and the extent of MSP, which is in accordance with the study by Sharan and Madjar [8]. This indicates that the MSP process is completed within 6 months. Thus, clinicians may anticipate a static location of the sinus floor even if implant placement is delayed for more than 6 months.

There are some limitations to the present study. First, in the 2-dimensional analysis, buccal and palatal sinus floor changes may overlap, and sinus pathology may not be accurately determined. Even though it is challenging to gather CBCT data pre-extraction and post-extraction in a large number of patients, future studies require an analysis based on 3-dimensional radiographs. Second, there was up to a 3-month difference between the date of extraction and the date of the pre-extraction panoramic radiograph. The extent of bone destruction around the target tooth may be different between these 2 time points.

In conclusion, maxillary sinus pneumatization was 1.56±3.93 mm on average. The extraction of second molars led to the greatest extent of pneumatization, which should be considered in treatment plans for this tooth site. The findings of the present study should be further investigated using 3-dimensional radiography.

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