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Original Article

Relation between maxillary sinus pneumatization and the thickness of the mandibular inferior border in panoramic radiographs

Nasim Jafari-pozve [a], Sayed Hanif EmamJome [b], Mahshad Saei [c,*]

[a] Department of Oral and Maxillofacial Radiology, School of Dentistry, Isfahan (Khorasgan) Branch, Islamic Azad University, Dental Implants Research Center, School of Dentistry, Isfahan University of Medical Sciences, Isfahan, Iran
[b] School of Dentistry, Islamic Azad University, Isfahan (Khorasgan) Branch, Isfahan, Iran
[c] School of Dentistry, Student Research Committee, Islamic Azad University, Isfahan (Khorasgan) Branch, Isfahan, Iran

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ABSTRACT

Background: Maxillary sinus pneumatization is a physiological process that can adversely affect bone availability for further dental rehabilitation. If a relation between the thickness of the mandibular cortex and maxillary sinus pneumatization is proven, future bone availability can be deducted.

Material and methods: In this cross-sectional study, 85 panoramic radiographs were evaluated. All patients were between 19 and 70, had at least lost a second premolar, first molar, or second molar on one side of the maxilla, and had these teeth on the other side. Four lines were digitally drawn on the radiographs to determine the superior and inferior borders of the sinus on both sides. The amount of inferior sinus border progression was deducted using the digitally-measured lines' ratios. The following tests were done using IBM SPSS ver. 24: Pearson's correlation coefficient test, Tukey's dual comparison posthoc test, One-way ANOVA test, and the independent T-test ($p = 0.05$).

Results: There was a negative correlation between the inferior mandibular cortex's thickness and the maxillary sinus's pneumatization ($p < 0.001$). Also, there was a significant difference between maxilla sinus pneumatization in the second premolar, first, and second molar areas based on the inferior mandibular cortex's thickness ($p = 0.009$).

Conclusions: Based on the present study, there is a significant relationship between the thickness of the inferior mandibular cortex and maxillary sinus pneumatization, especially for women and patients above 40 years old.

1. Introduction

The Maxillary sinus is the first paranasal sinus to develop at 17 weeks in utero (Whyte and Boeddinghaus, 2019). Many factors influence its pneumatization, including posterior tooth loss, bone density, heredity, and craniofacial configuration. Although physiological, maxillary sinus pneumatization might impose complications regarding bone-involving treatments (e.g., implant placement), and yet, it is poorly understood (Cavalcanti et al., 2018).

Osteoporosis is the loss of bone mass caused by an imbalance in bone resorption and formation. Patients with this condition are at a higher risk for fractures and pain, which will negatively affect their quality of life (Ezoddini Ardakani et al., 2013). Currently, osteoporosis is mainly diagnosed by measuring bone mineral density (BMD) via dual-energy X-ray absorptiometry. A correlation between BMD and mandibular indices, including the inferior mandibular cortical thickness, has been demonstrated through multiple studies. As such, the mandibular cortex may be used to evaluate patients regarding osteoporosis (Carmo and Medeiros, 2017; Mupparapu and Akintoye, 2023).

Radiological evidence suggests excessive pneumatization of the frontal and mastoid sinuses in children with severe osteoporosis (Rauch and Glorieux, 2000). This diagnostic feature hints at the possibility of excessive Maxillary sinus pneumatization in adults with osteoporosis; thus, the relationship between the thickness of the mandibular cortex and Maxillary sinus pneumatization may predict future bone availability for medical interventions.

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* Corresponding author at: School of Dentistry, Islamic Azad University Isfahan, Khorasgan Branch, University Blvd, Arqavanieh, Jey Street, Isfahan, Iran.
E-mail address: saie.mah9877@gmail.com (M. Saei).

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2. Material and methods

2.1. Study design

In this descriptive-analytical cross-sectional study, 85 panoramic radiographs were chosen from panoramic radiographs taken at the radiology department of Isfahan's (Khorasgan's) Islamic Azad University. The protocol of this study was approved by the research ethics committee of Isfahan's (Khorasgan's) Islamic Azad University. All images were taken with the "vetch pch 2500, GGenongi Korea" machine, set at 90–50 kVp, 4–10 mA, and 8.6–13.5 s exposure time. All images had good clarity and contrast, and the palatoglossal airway space was absent. Also, the radiographs had proper sagittal and horizontal focal trough positioning. The following landmarks were evident: 1. Molar teeth of maxilla 2. The floor of the maxillary sinus 3. Zygomatic process of maxilla 3. The inferior border of orbit 4. The inferior border of the mandible.

2.2. Patients

The patients were between the ages of 19–70 and had taken panoramic radiographs from March 21, 2019, until March 20, 2020. They must have had the closest teeth to the maxillary sinus (second premolar, first, and second molar) in one quadrant while having lost at least one of these teeth in the past 6–18 months in the opposing maxillary quadrant. Patients with the following criteria were excluded:

1. Developmental defects in the maxillofacial region.
2. Other bone diseases (Osteomyelitis, bone malignancies, bone metastases, etc.).
3. History of nasal or sinus diseases or sinus surgeries.
4. Systematic conditions and drug intakes affecting normal bone remodeling.

2.3. Maxillary sinus floor determination and comparison

Five lines were drawn using the Planmeca Romexis viewer version 3.8.3 on every radiograph: an interorbital line connecting the lowest points of the orbits, lines passing through the most inferior points of the sinus and zygomatic process lines (line passing through the most inferior point of each zygomatic process, on both sides). The distance between the interorbital line and zygomatic process line (IZ_X on the edentulous side, IZ_T on the dentate side), and the distance between the interorbital line and the inferior cortical border of the maxillary sinus (IS_X for each missing tooth, IS_T for each corresponding tooth in the opposite maxillary quadrant) were measured (Fig. 1). The position of the maxillary sinus floor was defined as a ratio (IS/IZ) to compensate for possible distortion.

The null hypothesis is "There is no difference between the levels of maxillary sinus floor on both sides." This statement is shown as $IS_x/IZ_x = IS_T/IZ_T$, from which the equation $IS_X - (IS_T * IZ_X/IZ_T)$ can be deducted. If the equation results in a positive value, the maxillary sinus floor on the edentulous side is lower than the maxillary sinus floor on the opposite side (Sharan and Madjar, 2008). For example, for the patient presented in Fig. 1, the equation results in a positive value (24.6 – (23 * 15.4/16.3), indicating excessive maxillary sinus progression of the edentulous side compared to the opposite side.

2.4. Determination of the thickness of the inferior mandibular cortex

The thickness of the inferior mandibular cortex was measured at the thickest section of the cortex (Usually below the 3rd molar region). A thickness between 4.2 and 3.2 mm was considered osteopenia, under 3.2 mm indicated osteoporosis and a thickness above 4.2 mm was considered normal (Carmo and Medeiros, 2017).

2.5. Statistical analysis

Using the IBM SPSS Statistics for Windows (Version 24.0. Armonk, NY: IBM Corp), mean, standard deviation, Pearson's correlation coefficient, and multivariant regressions were calculated. A P-value of < 0.05 was considered significant.

3. Results

3.1. Descriptive data

Eighty-five panoramic radiographs were evaluated (Table 1). The thickness of the inferior mandibular cortex indicated that 10.6 % were osteoporotic, 52.9 % had osteopenia, and 36.5 % were considered normal. Maxillary sinus pneumatization was reported to be between

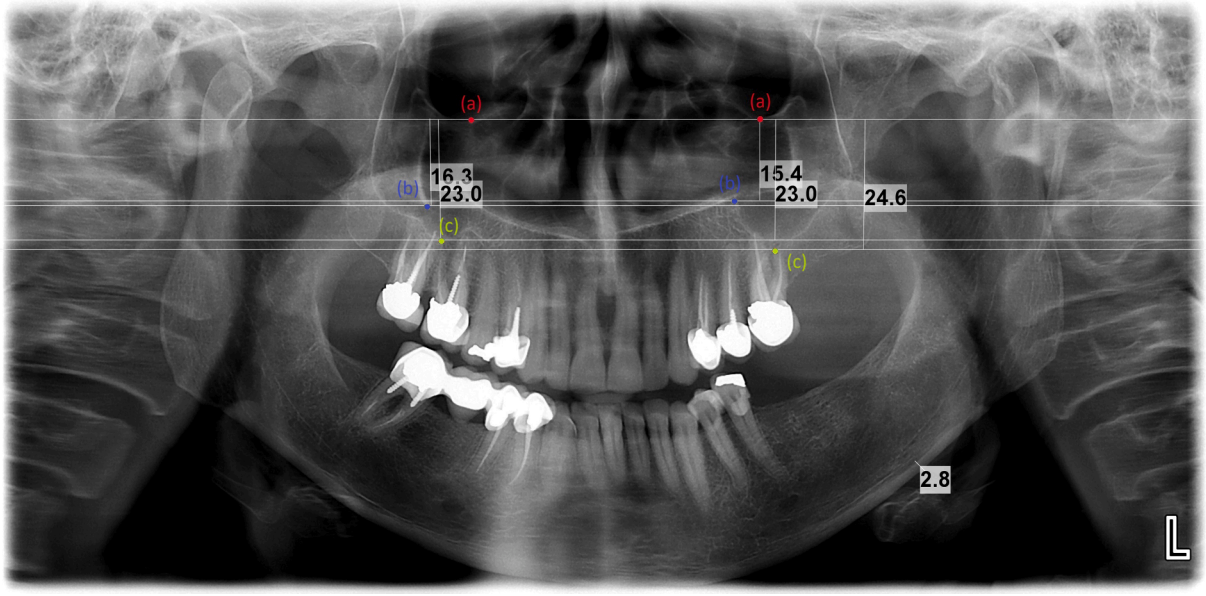

Fig. 1. Panoramic radiograph of a patient with osteoporosis (Inferior mandibular cortex thickness of 2.8 (mm)). (a) Most inferior points of the orbits and their connecting line (b) Most inferior points of the zygomatic process (c) Most inferior points of the maxillary sinus.

Table 1
Demographic Information.

Variable	Groups	n	Percentage	Mean (±SD)
Gender	Male	33	38.8 %	–
	Female	52	61.2 %	
Age	20–39	38	44.7 %	45.92
	40–59	27	31.8 %	(±15.41)
	60<	20	23.5 %	
Quadrant of tooth extraction	1	38	44.7 %	–
	2	47	55.4 %	
Tooth/Teeth extracted	First Molar	32	37.6 %	–
	Second Molar	22	25.0 %	
	Second Premolar	18	21.2 %	
	First Molar & Second Molar	5	5.9 %	
	First Molar & Second Premolar	5	5.9 %	
	First Molar & Second Molar & Second Premolar	3	3.5 %	
Time elapsed following tooth/ teeth extraction	6–9 months	27	31.8 %	–
	9–12 months	18	21.2 %	
	12–15 months	17	20 %	
	15–18 months	23	27.1 %	

−0.60 and 6 mm, and the mean was 2.622 ± 1.42 mm. The mean maxillary sinus pneumatization in normal, osteoporotic, and osteopenic patients was 2.12 ± 1.23 mm, 3.67 ± 1.62 mm, and 2.76 ± 1.39 mm, respectively.

3.2. The Pearson's correlation coefficient test

This test showed an inverse relationship between maxillary sinus pneumatization and the thickness of the inferior mandibular cortex for all patients ($p < 0.001$, $r = -0.384$). As for the sub-groups, there is a significant inverse relationship between maxillary sinus pneumatization and the thickness of the inferior mandibular cortex in the right and left quadrants for each patient. The same is true regarding the tooth/teeth lost and time elapsed after losing teeth, except within the 9–12 months group. Additionally, female patients and patients ≥40 years old showed a significant inverse relationship. In osteopenic patients, there is evidence of a significant inverse relationship. The correlation coefficient was also relatively strong in osteoporotic patients but was not considered significant because of the small number of samples (Table 2).

3.3. One-way ANOVA test

The One-way ANOVA test demonstrated a significant difference between the means of maxillary sinus pneumatization among normal, osteoporotic, and osteopenic patients ($P = 0.009$). A significant difference exists in maxillary sinus pneumatization between different tooth/ teeth losses (Table 3).

3.4. Tukey's dual comparison posthoc test

This test shows a significant difference between maxillary sinus pneumatization means of osteoporotic and normal patients ($P = 0.010$). Significant differences between means of maxillary sinus pneumatization in patients with 2–3 extracted teeth and second premolar ($P = 0.004$) or first molar ($P < 0.001$) extractions were evident. Means of maxillary sinus pneumatization for second and first molar extractions differed significantly (Table 4).

3.5. The independent T-test

There is a significant difference in maxillary sinus pneumatization between the normal and reduced (osteopenic and osteoporotic) thickness of the mandibular inferior cortex ($P = 0.012$) (Table 5).

Table 2
Coefficient correlation of inferior mandibular cortex thickness and maxillary sinus pneumatization of different groups.

Variable	Groups	n	Coefficient correlation	P-Value
Inferior mandibular cortex thickness and maxillary sinus pneumatization	Osteoporotic patients [A]	9	−0.582	0.100
	Osteopenic patients [A]	45	−0.270	0.073
	Normal patients [A]	31	−0.082	0.660
	Male	33	−0.291	0.101
	Female	52	−0.436	0.001
	Ages 20–39	38	−0.139	0.407
	Ages 40–59	27	−0.489	0.010
	Ages ≥ 60	20	−0.648	0.002
	Left maxillary quadrant	33	−0.355	0.029
	Right maxillary quadrant	52	−0.409	0.004
	6–9 months after tooth extraction	27	−0.468	0.014
	9–12 months after tooth extraction	18	−0.080	0.753
	12–15 months after tooth extraction	17	−0.707	0.002
	15–18 months after tooth extraction	23	−0.470	0.024
	First molar extracted	32	−0.587	<0.001
	Second molar extracted	22	−0.489	0.021
	Second premolar extracted	18	−0.517	0.028
	Two or three teeth extracted	13	−0.770	0.002

[A] For further information, seek Section 2.4.

4. Discussion

Osteoporosis is a bone-altering condition that can adversely affect bone density and cause mortality and morbidity. Early diagnosis and intervention will prevent severe problems. Mandibular indices measured in panoramic radiographs (e.g., Mental index (MI), panoramic mandibular index (PMI), and mandibular cortical index (MCI)) have long been used to assess one's risk of systematic osteoporosis (Ezoddini Ardakani et al., 2013; Munhoz et al., 2021; Sanfilippo and Bianchi, 2003). We chose the inferior cortex of the mandible since it is a well-established index for BMD evaluation and is relatively more accessible (Carmo and Medeiros, 2017; Mupparapu and Akintoye, 2023).

Rauch et al. have reported excessive mastoid and frontal sinus pneumatization in children with severe osteoporosis (Rauch and Glorieux, 2000). Similar to Sharan and Madjar, who proposed that bone level, volume, and density affect maxillary sinus pneumatization, Tolstunov et al. have suggested that maxillary sinus pneumatization increases with higher levels of bone resorption (Sharan and Madjar, 2008; Tolstunov et al., 2012). Our study confirms their findings, as patients with osteoporosis had higher levels of maxillary sinus pneumatization.

Our findings demonstrate that posterior tooth extraction (excluding third molars) in the maxilla significantly increases maxillary sinus pneumatization. Our study and the study by Padhye et al. demonstrate that the number of teeth lost in the same quadrant significantly affects sinus pneumatization; patients who had lost 2–3 teeth had greater degrees of sinus pneumatization compared to patients who had only lost a second premolar or a first molar (Padhye et al., 2021). Our findings are further supported by Sharen et al., who established that maximum pneumatization occurs following multiple posterior teeth extraction. In

Table 3
Comparison of maxillary sinus pneumatization between different groups, using the One-way ANOVA test.

Variable	Groups	n	Mean (±SD)	Statics	P-Value
maxillary sinus pneumatization towards the alveolar process	Ages 20–39	38	2.31 ± 1.27	F = 2.338	0.103
	Ages 40–59	27	3.07 ± 1.50		
	Ages > 60	20	2.62 ± 1.50		
	Osteoporotic patients [A]	9	3.67 ± 1.62	F = 5.046	0.009
	Osteopenic patients [A]	45	2.76 ± 1.39		
	Normal patients [A]	31	2.12 ± 1.23		
	6–9 months after tooth extraction	27	2.59 ± 1.58	F = 0.048	0.986
	9–12 months after tooth extraction	18	2.56 ± 1.48		
	12–15 months after tooth extraction	17	2.73 ± 1.05		
	15–18 months after tooth extraction	23	2.63 ± 1.50		
	First molar extracted	32	1.94 ± 1.07	F = 9.187	<0.001
	Second molar extracted	22	3.04 ± 1.74		
	Second premolar extracted	18	2.36 ± 1.11		
	Two or three teeth extracted	13	3.96 ± 0.76		

[A] For further information, seek Section 2.4.

Table 4
Tukey's dual comparison post-hoc test between different types of tooth/teeth loss.

Type (1)	Type (2)	Mean difference	P-Value
First Molar	Second molar	−1.096	0.012
	Second Premolar	−0.420	0.666
	Two or three teeth	−2.021	<0.001
Second molar	Second Premolar	0.675	0.332
	Two or three teeth	−0.925	0.158
Second Premolar	Two or three teeth	−1.600	0.004

Table 5
Comparison of maxillary sinus pneumatization between different groups, using the independent T-test.

Variable	Groups	n	Mean (±SD)	Statics	P-Value
maxillary sinus pneumatization towards the alveolar process	Male	33	2.83 ± 1.25	t = 1.090	0.279
	Female	52	2.49 ± 1.52		
	Reduced mandibular cortex thickness	54	2.91 ± 1.46	t = 2.566	0.012
	Normal mandibular cortical thickness	31	2.12 ± 1.23		
	Left maxillary quadrant	47	2.53 ± 1.35	t = 0.659	0.489
	Right maxillary quadrant	38	2.74 ± 1.52		

cases with one tooth extraction, adjacent roots will keep the sinus floor from excessive expansion (Sharan and Madjar, 2008). Furthermore, various teeth extractions (first or second premolar or first molar) have differing effects on maxillary sinus progression, probably due to differences in root morphology and quantity, the distance between root apices and maxillary sinus (the distance is less in the posterior maxilla), and bone density in different regions (Lim et al., 2021; Sharan and Madjar, 2008).

In line with the findings of Ikeda et al., a decrease in the thickness of the mandibular inferior cortex and an increase in maxillary sinus pneumatization was evident with age (Ikeda et al., 1998; Munhoz et al., 2021). We found a significant inverse relationship between the thickness of the mandibular inferior cortex and maxillary sinus pneumatization in patients 40 and above. These findings suggest that assessing the thickness of the mandibular inferior cortex might be a reliable method for predicting maxillary sinus progression in middle-aged patients, which can instigate better treatment planning and improve prognosis prediction of different treatment approaches.

Moreover, we established a significant inverse correlation between maxillary sinus pneumatization and thickness of the mandibular inferior cortex within 6–9, 15–12, and 15–18 months following tooth extraction. This correlation was more significant within 15–12 months, so rehabilitation interventions might best be done less than 12 months following extraction.

The most important limitation of this study is our small sample size. Due to COVID-19 conditions, the number of patients was reduced significantly. This condition led to an inability to follow patients following tooth extraction properly. The effect of this small sample size is particularly evident regarding the significant inverse correlation observed between maxillary sinus pneumatization and the thickness of the inferior mandibular cortex. While BMD seems to affect sinus pneumatization positively, the correlation coefficient of maxillary sinus pneumatization and inferior mandibular cortex thickness is only significantly inverse in women. This inverted correlation might be attributed to differences in age and gender distribution in our sample since age has been shown to contribute to sinus pneumatization alongside maxillary posterior teeth extraction. We encourage future studies to survey larger samples at different periods following extractions and better age and gender distributions. Also, the effect of the presence or extraction of the 3rd molars should be evaluated.

5. Conclusions

Herein we described and demonstrated the inverse relationship between the thickness of the mandibular inferior cortex and maxillary sinus pneumatization, particularly in women and patients older than 40. Evaluating the inferior mandibular cortex and scheduling precise recall periods following extractions is recommended as a viable way to predict sinus progression and screen for osteoporosis patients with reduced inferior mandibular cortex thickness. Our findings reinforce the evidence regarding the proper timing of implant placement in the maxilla to prevent sinus pneumatization complications.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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