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RESEARCH ARTICLE

Depression of the maxillary sinus anterior wall and its influence on panoramic radiography appearance

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Objectives: To clarify the depression aspect of the maxillary sinus anterior wall and to investigate its relationship with the panoramic image appearance of a diagonal line from the inferior part of the so-called panoramic innominate line to the medial portion of the orbital floor line.
Methods: Based on CT data, panoramic images were simulated for two typical cases with and without anterior wall depression. Next, on axial CT images of 1689 subjects (3378 sinuses) stored in our image database, the wall depths were measured and analyzed for their relationships with the panoramic appearances of the diagonal line, classified into invisible, obscure and clear patterns.
Results: Based on the simulation study, visualization of the diagonal line was verified to alter depending on the morphology of the anterior wall and the position of the panoramic image layer. In 408 (12.1%) sinuses, the diagonal line (clear and obscure patterns) could be seen on the panoramic image. The incidences of the obscure and clear patterns increased with increasing age groups. The mean wall depths were 2.91, 4.80 and 7.28 mm for the invisible, obscure and clear patterns, respectively. The clear pattern showed the highest value for the wall depth, followed by the obscure pattern.
Conclusions: The diagonal line on a panoramic image was verified to be related to depression of the maxillary sinus anterior wall, and its panoramic image appearance can be altered depending on the position of the tomographic image layer.
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Introduction

Although panoramic radiography has been recognized as an essential tool in dental practice for more than half a century, panoramic image appearances are occasionally difficult to interpret, especially for structures adjacent to the maxillary sinus.[1] This can be mainly attributed to the complexity of anatomical variations in the maxillary sinus area and their relationships with X-ray beam projection angles in panoramic radiography. Meanwhile, CT and CBCT for dental use enable us to clearly visualize the anatomical structures adjacent to the maxillary sinus, and many studies have been performed on various diseases[2,3] and maxillary sinus morphologies, including volume[4,5] and sinus septa.[6] However, the knowledge obtained in these studies cannot completely contribute towards improvements in the interpretation of panoramic image appearances. In this regard, we focused on variants of the anterior wall of the maxillary sinus and the related appearances on panoramic radiographs in the present study.

On panoramic images, a characteristic diagonal line can occasionally be observed from the lower part of the

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so-called panoramic innominate line[7] to the medial portion of the orbital floor line. This line is represented as the side of a radiolucent right-angled triangle observed in the maxillary sinus area after Caudwell–Luc surgery.[8] However, it can also be clearly observed in some patients without this surgery. Taking the panoramic layer into account, this characteristic line on a panoramic image would be relevant to depression of the anterior wall and exaggeration of the combined area of the maxilla and zygoma.[8]

The aims of the present study were to clarify the depression aspect of the maxillary sinus anterior wall and to investigate its relationship with the panoramic image appearance. For these purposes, a simulation was first performed for the diagonal line based on the relationship between the morphology of the anterior wall and the panoramic image layer. Next, stored image data were reviewed for maxillary sinus anterior wall depression on axial CT images in relation to age, sex and panoramic image appearance.

Methods and materials

Simulation study

CT data for two typical subjects, one (Case A) without anterior wall depression (Figure 1a,b) and the other (Case B) with anterior wall depression (Figure 1c,d), were selected for the simulation. Each panoramic image was simulated using the ray summation (Raysum) function equipped in image-processing software (AquariusNET; TeraRecon Inc., Foster City, CA). The centre of the assumed panoramic image layer was determined based on the mandibular dental arch by reference to a reconstructed axial image parallel to the Frankfurt horizontal (FH) plane at the slice of the alveolar ridge (Figure 2). Panoramic images were simulated using the Raysum function. As the software could only create linear Raysum images, the rotation centre of each Raysum image with 20-mm thickness was set at the mandibular first molar on the axial image and its direction was set on the determined panoramic image layer (Figure 2). The layer and resulting Raysum image were defined as the centre layer and centre image, respectively. Two other Raysum images (inner and outer images) were created parallel to the centre layer with 5-mm distances. The resulting simulation images were investigated in comparison with the actual panoramic images.

The present study was approved by the ethics committee at the Aichi-Gakuin University (No. 471).

Image database review

Subjects were selected from the image database of our department between January 2014 and December 2016 based on the following criteria: subjects who received both panoramic and CT examinations and were evaluated both for right and left maxillary sinuses; and subjects with CT images including sequential slices from the orbital floor to the maxillary alveolar ridge. Subjects with cleft palate, tumours including the maxillary sinus and inflammation with severe symptoms at examination were excluded.

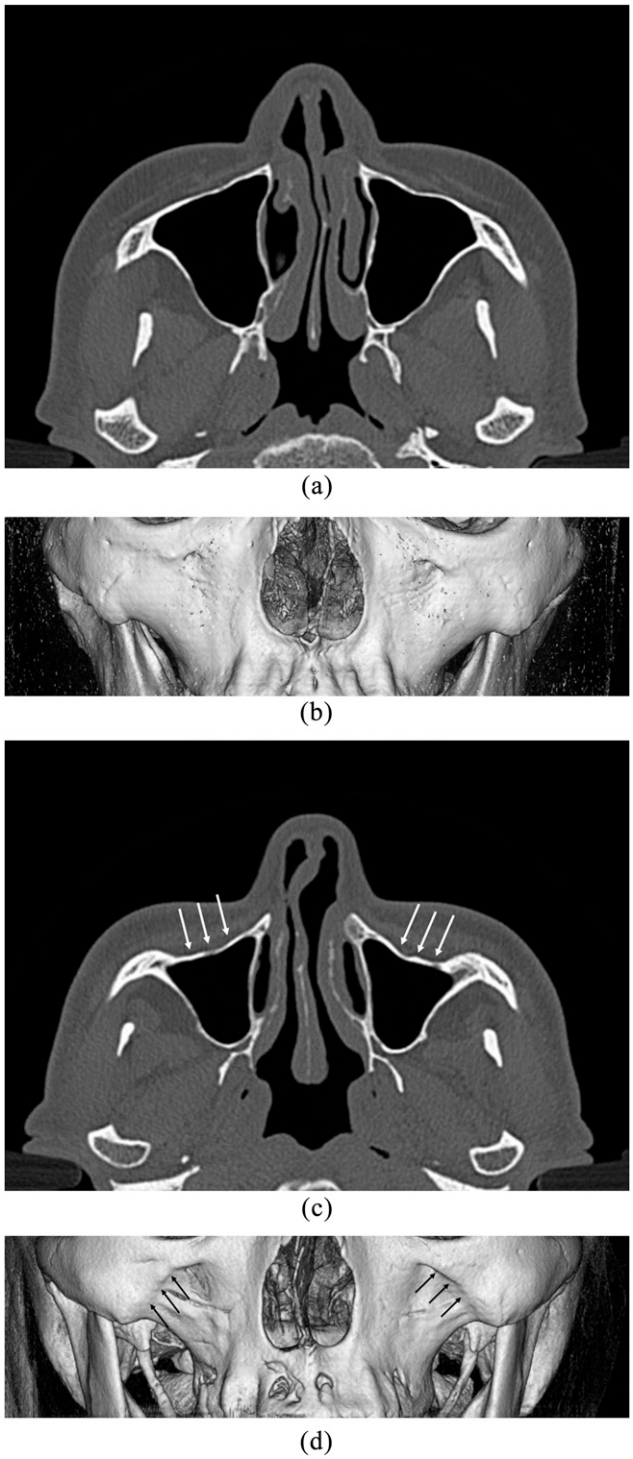

Figure 1 Typical appearances of the maxillary sinus anterior wall on axial CT (a, c) and three-dimensional (b, d) images. Case A without anterior wall depression (a, b). Case B with anterior wall depression (c, d). Arrows show the depressed portions.

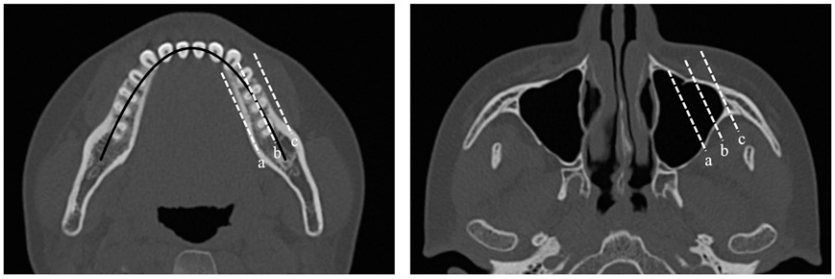

Figure 2 The inner (a), centre (b) and outer (c) layers for simulation of panoramic images at the levels of the mandibular arch and maxillary sinus.

Patients with a history of Caldwell–Luc surgery and/or definite image findings suggesting a post-operative state in the maxillary sinus were also excluded. Consequently, a total of 1689 patients (963 females and 726 males) were evaluated bilaterally. The subject distribution in relation to nine age groups is shown in Table 1.

Panoramic image classification

The appearance of the diagonal line was classified into three patterns: invisible, obscure and clear. The invisible pattern had no signs of the line. The obscure pattern was defined as a partially visualized or very thin feature of the line. The clear pattern had a continuous line that was clearly observed from the inferior edge of the so-called panoramic innominate line to the medial part of the orbital floor line (Figure 3). For actual evaluations, two observers (KY and MF) evaluated the patterns and reached final decisions by consensus and discussion when the initial evaluations were different. Before the actual evaluations, the interobserver and intraobserver agreements were tested on 30 randomly selected panoramic images by three observers (KY, MF and EA) using Cohen's kappa statistics modified for many observers and multiple categories.[9–11] The interobserver agreements of the three observers were 0.73 for the first evaluation and 0.80 for the second evaluations, showing substantial or almost perfect agreement. The intraobserver agreements were 0.85, 0.90 and 0.80 for the three observers, showing almost perfect agreement.

Measurement on CT images

To analyze the depression aspect of the maxillary sinus anterior wall, an axial Raysum image was created parallel to the FH plane using the slices from the orbital floor to the alveolus, thereby including the anterior nasal spine (ANS) and the most depressed portion of the maxillary sinus anterior wall (Figure 4). On the image, a tangential line to the anterior border of the zygomatic process of the maxilla was created from the ANS, and the distance was measured from the tangential line to the most depressed portion of the anterior wall, defined as the wall depth. The measurement error (e) was verified before actual measurements using Dahlberg's formula: $e=\sqrt{\sum(d^2/2n)}$ (d, the difference between the values in two measurements; n, number of subjects). Randomly selected Raysum images of 20 subjects (40 sinuses) were measured twice for the wall depth by one observer (KY). The measurement error was 0.32 mm and was thus relatively small compared with the mean wall depth of 3.18 mm.

Statistical analysis

The Tukey–Kramer test was applied for differences in the wall depths of the three panoramic patterns. Unpaired and paired t-tests were used to test the differences in wall depths between males and females and between right and left sinuses, respectively. The relationship between the mean age of each age group and the mean of wall depth was analyzed by Pearson's correlation coefficient. p-values of <0.05 were regarded as significant.

Table 1 Age distribution of panoramic patterns and depression of the maxillary sinus anterior wall on CT

Age (years)			*Panoramic patterns of the diagonal line*						
			Invisible		*Obscure*		*Clear*		
Age group	*Mean*	*Number of sinuses*	*Number of sinuses*	*%*	*Number of sinuses*	*%*	*Number of sinuses*	*%*	*Mean of the wall depth (mm)*
<10	7.5	392	387	98.7	5	1.3	0	0	2.60
11–20	16.1	592	562	94.9	29	5.0	1	0.2	2.59
21–30	23.8	582	541	93.0	39	6.7	2	0.3	2.82
31–40	35.2	394	365	92.6	29	7.4	0	0	2.98
41–50	45.5	390	354	90.8	32	8.2	4	1.0	3.27
51–60	54.9	314	271	86.3	40	12.7	3	1.0	3.22
61–70	65.0	324	246	75.9	63	19.4	15	4.6	3.93
71–80	75.1	272	171	62.9	72	26.5	29	10.7	4.64
>80	84.7	118	73	61.9	35	29.7	10	8.5	4.84
Total	37.8	3378	2970	87.9	344	10.2	64	1.9	3.18

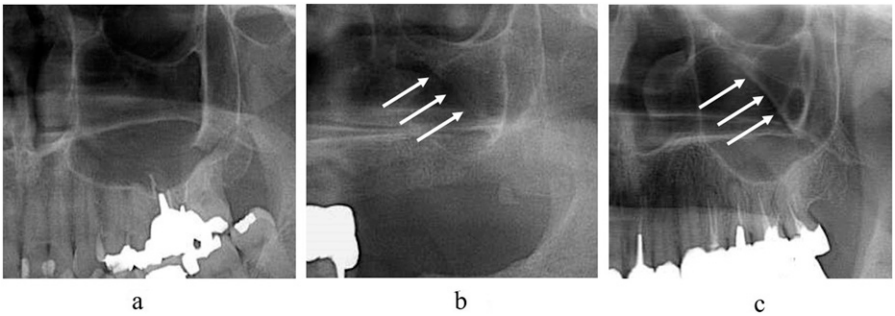

Figure 3 Visualization patterns of the diagonal lines. Invisible pattern (a). Obscure pattern (b). Clear pattern (c). Arrows show the diagonal lines.

Results

Simulation study

The diagonal line could not be observed on any of the three simulated panoramic images in Case A without maxillary sinus anterior wall depression (Figure 5). On the simulated panoramic image at the centre and outside image layer, the diagonal line could be observed in Case B with maxillary sinus anterior wall depression (Figure 6). Visualization of the diagonal line was verified to alter depending on the morphology of the anterior wall and the position of the panoramic image layer.

Image database review

A total of 408 (12.1%) sinuses showed the diagonal line (clear and obscure patterns) on the panoramic image. The incidences of the obscure and clear patterns on the panoramic images increased in an age-group-dependent manner, whereas that of the invisible pattern decreased (Table 1). In approximately 35% of subjects in the over-70s age group, the diagonal line could be observed as the obscure or clear pattern. Regarding the difference between the right and left maxillary sinuses, almost all subjects (1516 subjects; 89.8%) showed the same patterns. 23 (1.5%) and 147 (9.7%) subjects showed clear and obscure patterns and obscure and invisible patterns, respectively, whereas only 3 (0.2%) subjects showed clear and invisible patterns.

Figure 4 Measurement of wall depth.

The mean wall depths were 2.91, 4.80 and 7.28 mm for the invisible, obscure and clear patterns, respectively, and differed significantly from one another (Table 2, Figure 7). The clear pattern showed the highest value for the wall depth, followed by the obscure pattern.

A significant difference was found between the mean wall depths in males (3.26 mm) and females (3.12 mm) ($p = 0.005$). No difference was found in the wall depths between the right and left sinuses ($p = 0.14$).

The correlation coefficient was 0.95 ($p < 0.001$) between the means of age and wall depth. The wall depth also increased according to increasing age groups (Table 1).

Discussion

The appearances of structures around the maxillary sinus on panoramic images are complicated and sometimes difficult to interpret. Several lines, such as the orbital and sinus floor lines, medial and posterior wall lines, and so-called panoramic innominate line, create the characteristic appearance of this area on panoramic images. Among these, a diagonal line can occasionally be observed from the inferior part of the panoramic innominate line to the medial portion of the orbital floor line. This diagonal line is regarded as a characteristic feature after Caudwell–Luc surgery. Ohba et al[8] investigated the post-operative appearances on panoramic images in comparison with CT features and described the line as the side of a radiolucent right-angled triangle at the maxillary sinus area. The radiolucent triangle was considered to be related to the retracted maxillary sinus after the surgery and to arise through the characteristic radiography projection angle and depressed anterior and posterior walls of the sinus.[8] On clinical images, the line can also occasionally be observed in patients with no evidence of this surgery. Based on the cited report and our simulation study, the diagonal line may be related to the maxilla between the upper part of the zygomaticoalveolar crest and the canine fossa corresponding to the maxillary

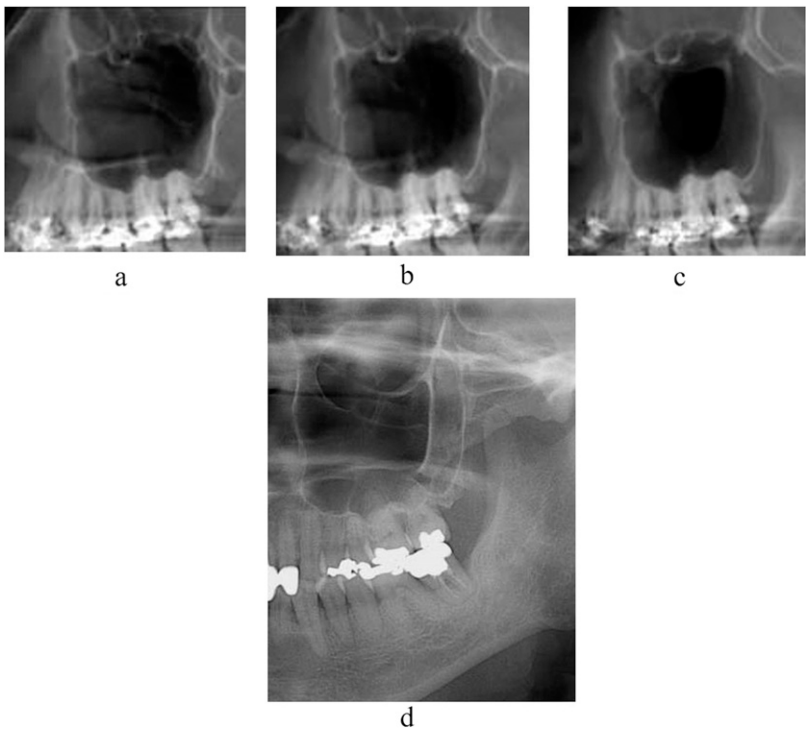

Figure 5 The inner (a), centre (b) and outer (c) images simulated at the layers of Figure 2 show no evidence of the diagonal line in Case A without maxillary sinus anterior wall depression. On the actual panoramic image (d), the line also cannot be observed.

sinus anterior wall. Visualization of the line can be partially explained as follows: the panoramic X-ray beam generally passes through the anterior wall at near right angle, not at tangential angle, resulting in no visualization of the wall. However, the beam passes tangentially through a part of the depressed wall

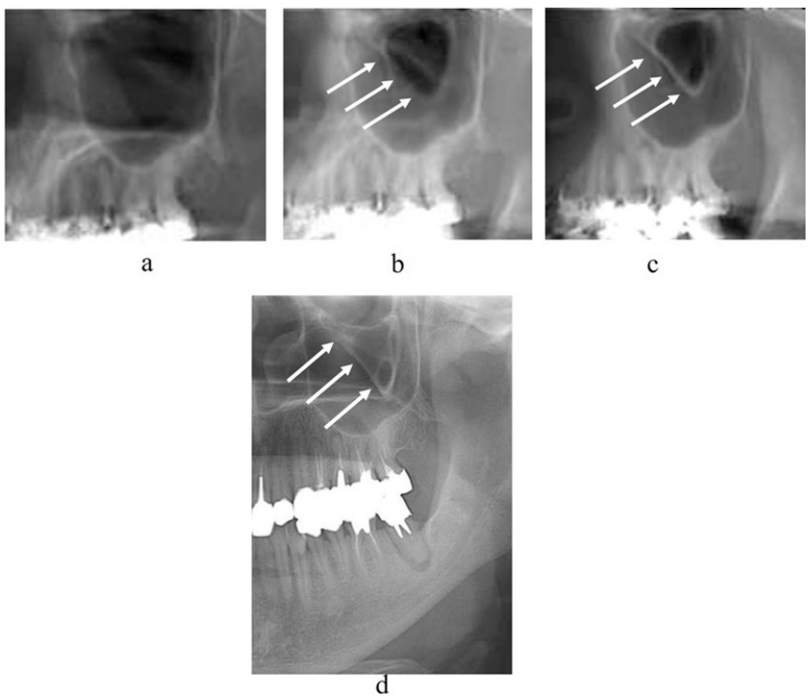

Figure 6 On the centre (b) and outer (c) simulated images, the diagonal line is clearly depicted (arrows), whereas no line can be observed on the inner simulated image (a). The actual panoramic image shows the diagonal line (arrows) (d).

Table 2 Relationship between panoramic appearances and wall depth

		Panoramic appearances of the diagonal line		
	Side	*Invisible*	*Obscure*	*Clear*
Wall depth (mm)	Right side	2.87 (0.11–10.05)	4.86 (0.54–11.04)	7.46 (4.19–10.85)
	Left side	2.95 (−0.22–9.73)	4.73 (0.20–11.22)	7.14 (4.20–11.72)
	Overall	2.91	4.80	7.28

representing the radio-opaque line. Depression of the anterior wall may exaggerate the anterior protrusion of the combined area of the maxilla and zygoma, resulting in clear visualization of the diagonal line. Thickening and sclerotic changes of the zygomatic arch may also enhance the visibility of the line.

The Raysum method, which was used to simulate panoramic images in the present study, is a three-dimensional image-processing procedure that creates images based on the average signal (CT value) along assumed X-ray routes and can simulate images that resemble conventional radiographs. It can also produce tomographic-like images when the reconstructed thickness is limited to the tomographic layer. As the mid-portion of the diagonal line can usually be observed in the molar region, the centre of the simulated panoramic image layer was set at the mandibular first molar on axial CT images in the present study. The axial CT images were created parallel to the FH plane because the ordinary panoramic images were taken with the FH plane in the horizontal position. Although the thickness of the panoramic image layer was generally approximately 15 mm in this position, the simulated layer was set at 20-mm thickness. The Raysum images could not include data outside of the assumed thickness, whereas the panoramic images included data outside of the layer. This method may be effective for clarifying panoramic image construction in future studies. The anterior wall depression was also measured on Raysum images created parallel to the FH plane. The Raysum images included the ANS and the most depressed portion of the anterior wall, thereby allowing the performance of sufficiently reliable measurements. The measurement error was verified to be small.

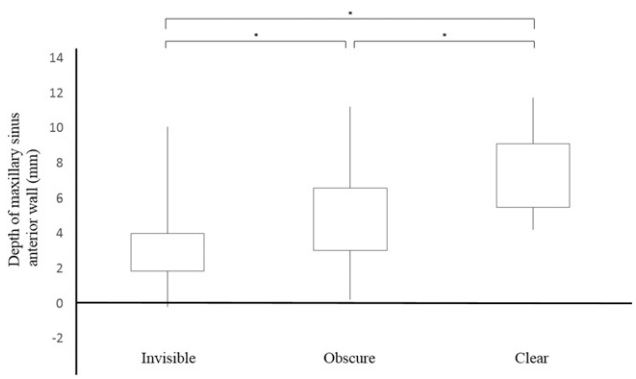

Figure 7 Panoramic patterns of the diagonal lines and wall depths. *$p < 0.0001$, significant difference.

The clear pattern showed the deepest anterior wall depression, followed by the obscure pattern. The invisible pattern showed the shallowest depression. Accordingly, the panoramic appearance of the line was verified to alter depending on the depth of the maxillary sinus anterior wall depression. Although the present study was a cross-sectional study, the wall depth increased in relation to increasing age groups. Similar results of age-related reductions were reported in a cross-sectional study on sinus volume.[4] Therefore, the reduction in sinus volume could be partially attributed to anterior wall depression.

The arguments of silent sinus syndrome, which is characterized by painless facial asymmetry and enophthalmos caused by chronic maxillary sinus atelectasis, may contribute to discussions on the cause of the anterior wall depression addressed in the present study. Based on a previous image investigation study on this syndrome, outlet obstruction and occupation by water and/or soft-tissue structures are characteristic features in the affected sinus together with sinus volume decrease caused by inward retraction of the maxillary sinus walls including the anterior wall.[12] Hourany et al[13] reported a case of this syndrome with history of surgical intervention for a post-traumatic nasal septum deformity and verified the existence of an acquired nature for this pathology. Thus, the possibility of an acquired nature is also suggested for anterior wall depression. However, as mentioned by Ariji et al[4] for the sinus volume, a longitudinal study is required for the final determination. A possible explanation for the wall retraction is the presence of negative intrasinus pressure caused by gas resorption following obstruction of the sinus ostium, in a similar manner to middle ear atelectasis caused by eustachian tube pathology.[12,13] However, this remains uncertain, taking the high frequency of ostium obstruction and the low prevalence of the syndrome into account. Meanwhile, increasing the chance to expose to such events in elderly persons may be a cause of increasing the wall depth with age. Therefore, a future study should be conducted to clarify the status of ostium obstruction together with preceding trauma and surgery for cases with anterior wall depression.

In conclusion, the diagonal line on a panoramic image investigated in the present study was verified to be related to depression of the maxillary sinus anterior wall, and its appearance can be altered depending on the position of the panoramic image layer.

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