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Experimental Study of Maxillary CT

APPLICATION OF CT IN DIAGNOSING CARCINOMA OF THE MAXILLARY SINUSES

PART 2: AN EXPERIMENTAL STUDY OF PITFALLS ENCOUNTERED WHEN DIAGNOSING CARCINOMA OF THE MAXILLARY SINUSES WITH CT.

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ABSTRACT

A phantom simulating the transverse section of the maxillary sinuses was constructed for experimentation with various CT scanners to study the following: (1) the occasional inability to image the very thin posterior-lateral walls which have no real bone defects, and (2) to verify whether or not the bony walls surrounding the maxillary sinuses are actually as thick as they appear on CT. The phantom was made of an acrylic cylinder containing three cavities simulating the maxillary sinuses and the nasal cavity and filled with water. The walls, made of thin aluminum and acrylic plates and placed between water and air, disappeared in some CT images. The thickness of the walls calculated from CT values was greater than the true thickness imaged by each CT scanner. The author stresses that in CT images, either experimentally or clinically, thin bony walls placed between water and air or fat tend to disappear, and that bony walls tend to appear thicker than their true thickenss.

Key words: CT, phantom experiments, maxillary sinus, CT value, bony wall thickness

INTRODUCTION

Various phantoms have been used to evaluate the performances of CT scanners[1)-8)], but a phantom simulating the maxillary region has seldom been used. We made a phantom simulating the transverse section of the maxillary sinuses in order to experimentally study the performances of various CT scanners when imaging (1) very thin unaffected bony walls, such as the posterior-lateral walls of the maxillary sinuses, and their occasional disappearance in CT images, and (2) why bony walls surrounding the maxillary sinuses tend to be visualized thicker in CT images than in vivo.

METHODS

The phantom was made of an acrylic cylinder with an outside diameter of 15 cm and walls of 0.5 cm in thickness. Three cavities simulating the bilateral maxillary sinuses and the nasal cavity were made (Fig. 1), after which the phantom was filled with water. The wall simulating the lateral wall of the right maxillary sinus (Wall A), its medial wall (Wall B), its anterior wall

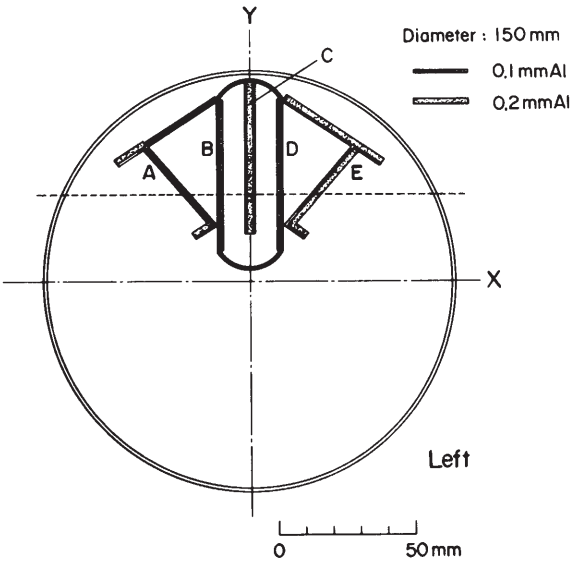

Fig. 1. A transverse section of the phantom.
The broken line indicates the level corresponding to the posterior portion of the maxillary sinuses.

(unmarked), and the medial wall of the left maxillary sinus (Wall D) were made of acrylic plates (1 mm thickness) and aluminum plates (0.1 mm thickness). The wall simulating the lateral wall of the left maxillary sinus (Wall E), its anterior wall, the bilateral zygomatic bones, and internal and external pterygoid processes were made of acrylic plates (1 mm thickness) and aluminum plates (0.2 mm thickness). The wall simulating the the nasal septum (Wall C) was made of an aluminum palte (0.2 mm thickness) placed between two acrylic plates (1 mm thickness).

The experiments were conducted under the following four conditions: (1) the three cavities simulating the bilateral maxillary sinuses and the nasal cavity were filled with air (Experiment 1); (2) the cavity simulating the right maxillary sinus was filled with water, and the cavities simulating the nasal cavity and the left maxillary sinus were filled with air (Experiment 2); (3) the cavities simulating the right maxillary sinus and the nasal cavity were filled with water, and the cavity simulating the left maxillary sinus was filled with air (Experiment 3); and (4) all the cavities were filled with water (Experiment 4).

CT images of the phantom were taken with the following three CT scanners, Delta-2020 (Scanner I), GE-CT/T 8800 (Scanner II), EMI-1010 (Scanner III) with 1 cm collimation at 120 kV. The computed areas of Scanners I and II were both 25 cm, and the area of Scanner III was 24 cm. Their matrix numbers were 512×512, 320×320, 160×160 respectively, and their pixel sizes were 0.488×0.488 mm, 0.8×0.8 mm, 1.5×1.5 mm respectively.

The CT images (displayed with constant window widths and levels) and the CT values were analyzed. The CT values at the level corresponding to the posterior portion of the maxillary sinuses (Fig. 1) were plotted. The average peak X-axis CT values of Walls A to E at the level corresponding to the posterior portion of the maxillary sinuses were calculated from the

wall's peak CT values and were made up of 17 pixels (8.3 mm) in Scanner I, 11 pixels (8.8 mm) in Scanner II, and 6 pixels (9 mm) in Scanner III. The average thickness of Walls A through E at the same level as was given above were calculated in the same manner. Here, the border of two neighboring substances was presumed to be half the value of the differences of their CT values[9].

CT image measurements of the thickness of the lateral and medial walls of the maxillary sinuses at the posterior portion of the maxillary sinuses were taken in 20 clinical cases with Scanners I and III, and no paranasal abnormalities were noted. The thickness of the walls measured in CT images was compared with the thickness calculated from CT values for one case.

RESULTS

CT images of the phantom taken by the three CT scanners are shown in Figures 2, 3, and 4. Wall A and the wall simulating the anterior wall of the right maxillary sinus (Fig. 2A), Wall B (Fig. 2B) and Wall D (Fig. 2C), which were made of acrylic plates (1 mm thickness) and aluminum plates (0.1 mm thickness), disappeared when CT images were taken by Scannner I. This phenomenon was found when the walls were placed between water and air at various CT window widths and window levels. This phenomenon was not found when CT images were taken by Scanners II (Fig. 3) and III (Fig. 4), but the thickness of the walls imaged by each CT scanner seemed to be thicker than their true thickness. Graphs of CT values illustrating these phenomena are presented in Figures 5–7. The values for every wall placed between water and air, except Wall E which was made of an acrylic plate (1 mm thickness) and an aluminum plate (0.2 mm thickness), did not form any peaks but rather formed shoulder-like CT value patterns in Scanner I (Fig. 5). The average experimental peak CT values of Walls A to E are shown in Fig. 8.

There was a significant CT value difference (more than 3 S.Ds.) involving the placement of Wall B in Experiments 1 and 2. The wall was surrounded by air in Experiment 1, and it was placed between water and air in Experiment 2. Scanners I, II, and III were used in both experiments. There was also a significant CT value difference between Experiments 2 and 3. Wall D was surrounded by air in Experiment 2, and was placed between water and air in Experiment 3. Scanners I, II, and III were again used in these studies.

The average thickness of the walls was greater than their true thickness for all three CT scanners, but with Scanner II the average thickness was not so great (Table 1).

The thickness of the lateral and medial walls of the maxillary sinuses measured in the CT images was greater than that of normal human patients who were measured after death (Table 2).

The thickness of the lateral and medial walls of the maxillary sinuses in one case imaged by Scanners I and III was smaller than those measurements calculated from the CT values imaged by Scanner I (Table 3).

There have been cases of pre-diagnosed carcinoma of the posterior-lateral walls of the maxillary sinuses in which these structures appeared to have bone defects in the CT images, but no bone defects were found upon operation (Fig. 9).

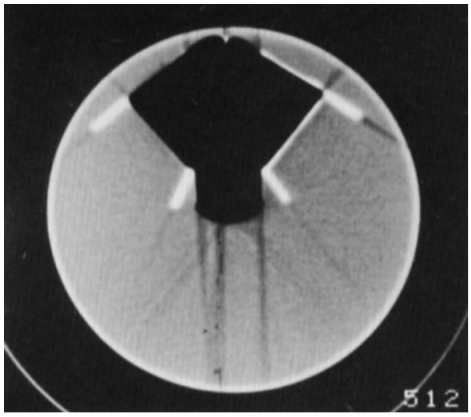

Fig. 2A. CT image of the phantom taken by Scanner I in Experiment 1. Wall A and the wall simulating the anterior wall of the right maxillary sinus disappeared.

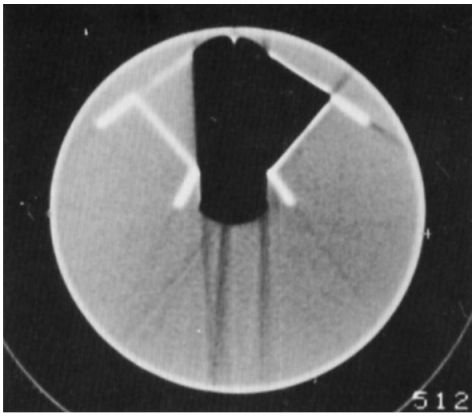

Fig. 2B. CT images of the phantom taken by Scanner I in Experiment 2. Wall B disappeared.

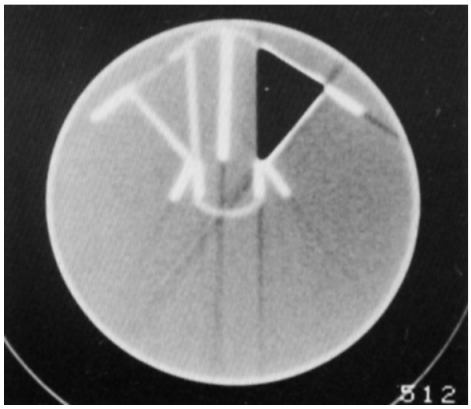

Fig. 2C. CT image of the phantom taken by Scanner I in Experiment 3. Wall D disappeared.

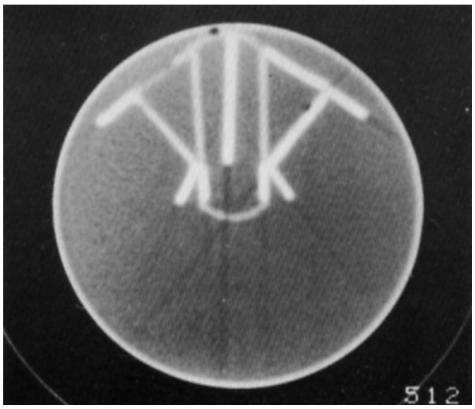

Fig. 2D. CT image of the phantom taken by Scanner I in Experiment 4.

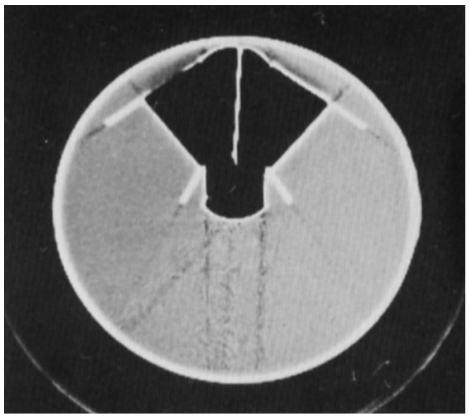

Fig. 3A. CT image of the phantom taken by Scanner II in Experiment 1.

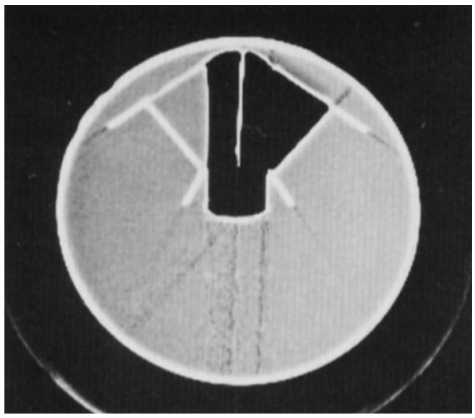

Fig. 3B. CT image of the phantom taken by Scanner II in Experiment 2.

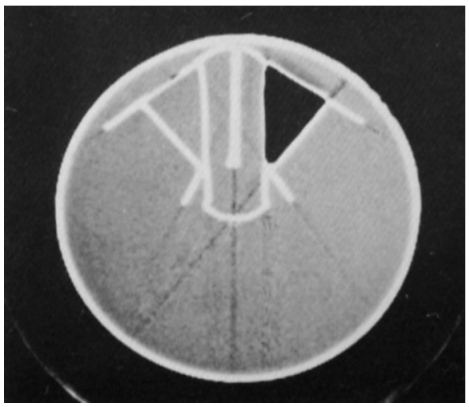

Fig. 3C. CT image of the phantom taken by Scanner II in Experiment 3.

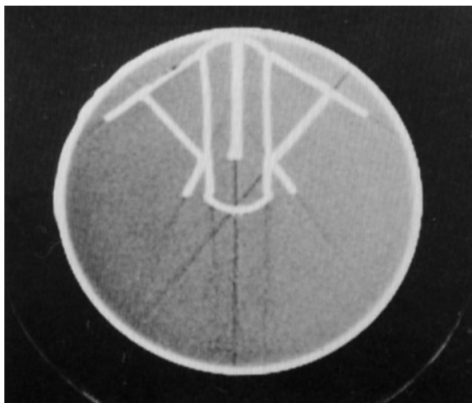

Fig. 3D. CT image of the phantom taken by Scanner II in Experiment 4.

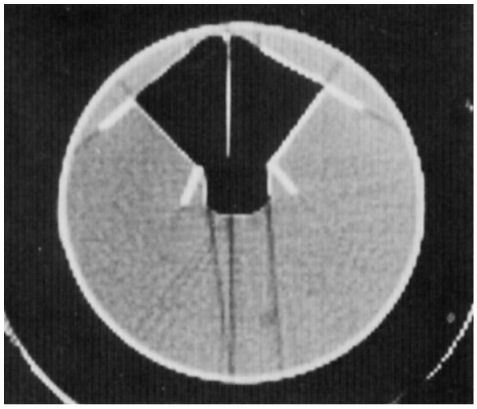

Fig. 4A. CT image of the phantom taken by Scanner III in Experiment 1.

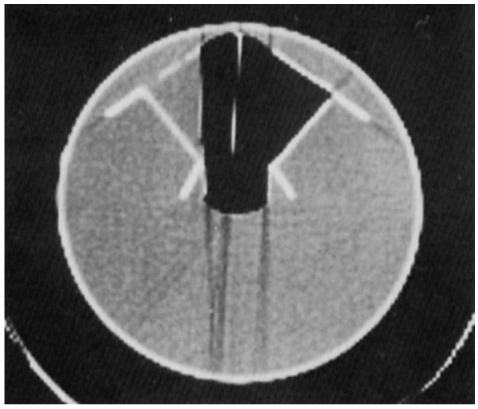

Fig. 4B. CT image of the phantom taken by Scanner III in Experiment 2.

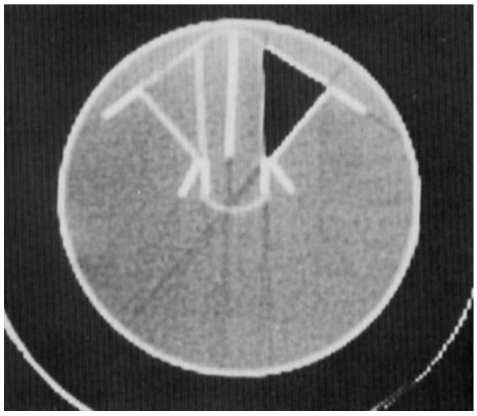

Fig. 4C. CT image of the phantom taken by Scanner III in Experiment 3.

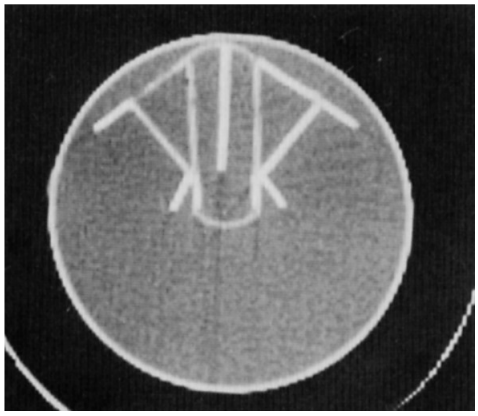

Fig. 4D. CT image of the phantom taken by Scanner III in Experiment 4.

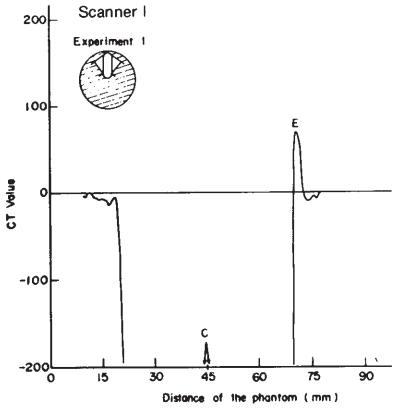

Fig. 5A. CT values at the level of the phantom corresponding to the posterior portion of the maxillary sinuses in Scanner I in Experiment 1.

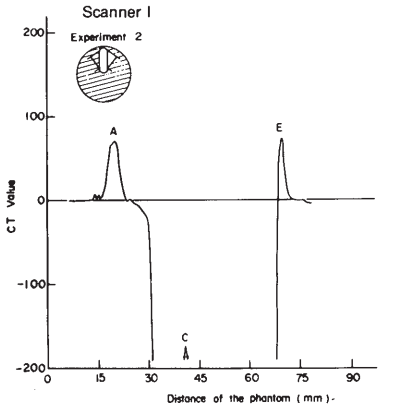

Fig. 5B. CT values at the same level as Fig. 5A. in Scanner I in Experiment 2.

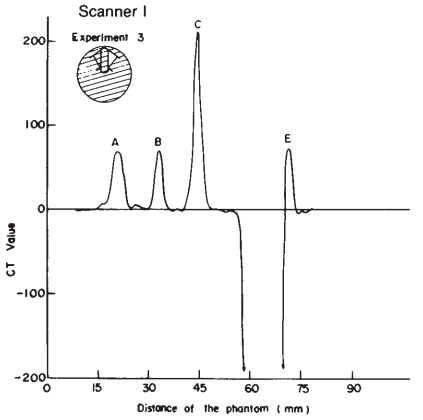

Fig. 5C. CT values at the same level as Fig. 5A. in Scanner I in Experiment 3.

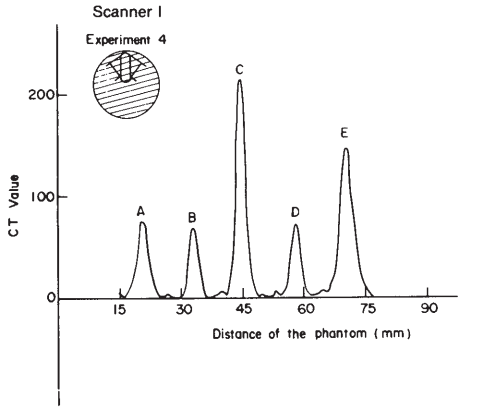

Fig. 5D. CT values at the same level as Fig. 5A. in Scanner I in Experiment 4.

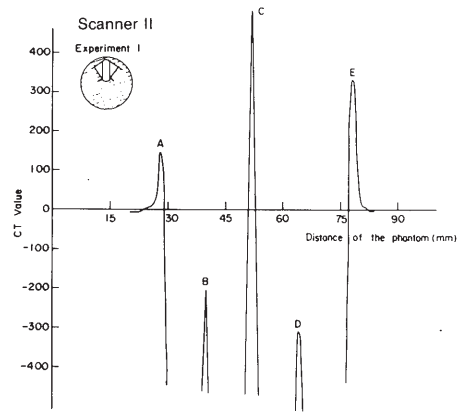

Fig. 6A. CT values at the same level as Fig. 5A. in Scanner II in Experiment 1.

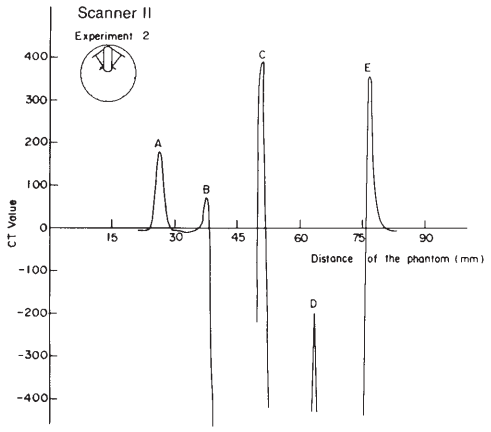

Fig. 6B. CT values at the same level as Fig. 5A. in Scanner II in Experiment 2.

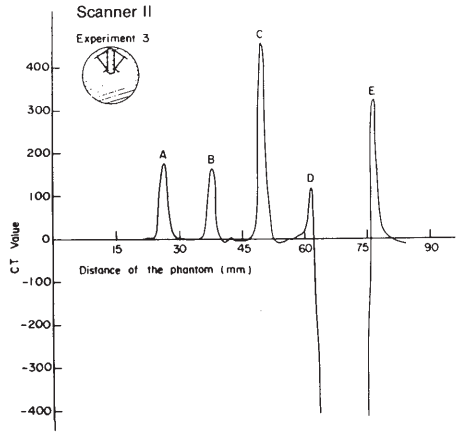

Fig. 6C. CT values at the same level as Fig. 5A. in Scanner II in Experiment 3.

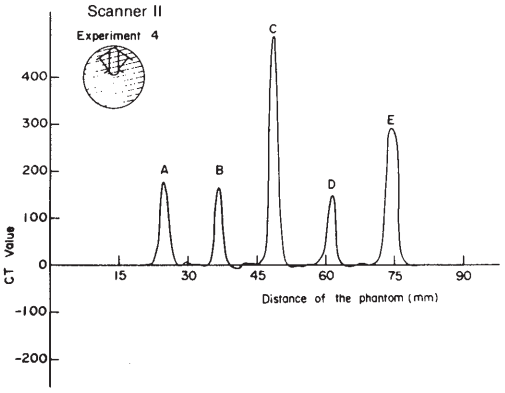

Fig. 6D. CT values at the same level as Fig. 5A. in Scanner II in Experiment 4.

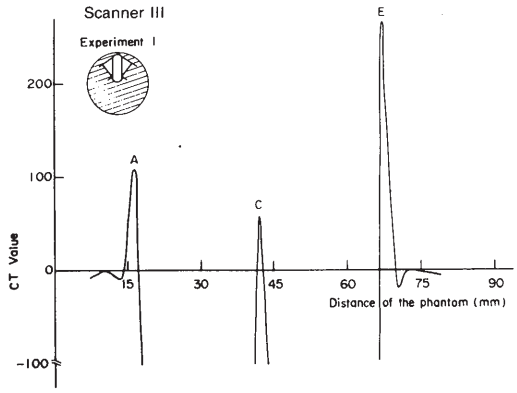

Fig. 7A. CT values at the same level as Fig. 5A. in Scanner III in Experiment 1.

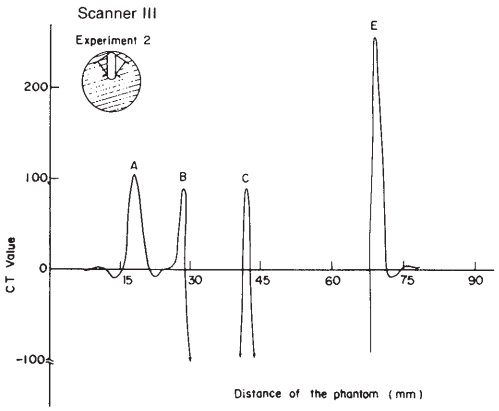

Fig. 7B. CT values at the same level as Fig. 5A. in Scanner III in Experiment 2.

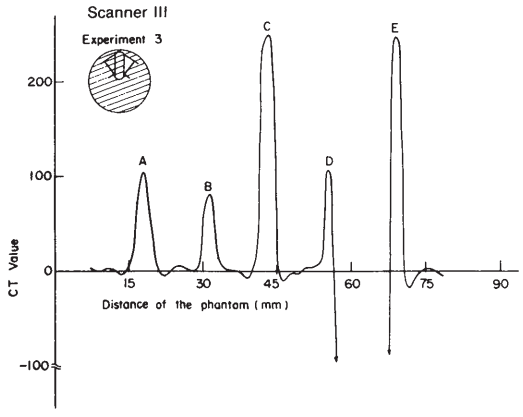

Fig. 7C. CT values at the same level as Fig. 5A. in Scanner III in Experiment 3.

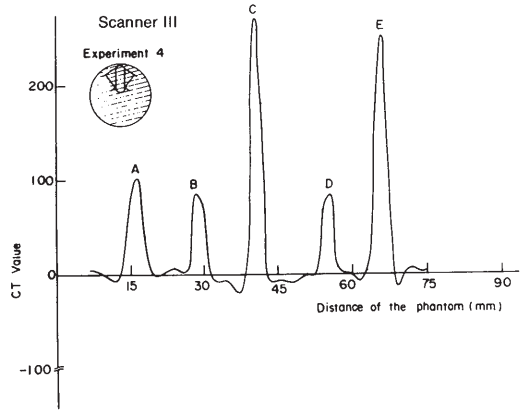

Fig. 7D. CT values at the same level as Fig. 5A. in Scanner III in Experiment 4.

WALL	EXPERIMENT NO.	Thickness of the walls calculated from CT values (mm)		
		Scanner I mean ± S.D.	Scanner II mean ± S.D.	Scanner III mean ± S.D.
A	1	–	2.3 ± 0.1	–
	2	2.9 ± 0.1	2.1 ± 0.2	3.4 ± 0.1
	3	3.0 ± 0.2	2.2 ± 0.1	3.5 ± 0.1
	4	2.9 ± 0.1	2.3 ± 0.2	3.5 ± 0.1
B	1	3.3 ± 0.1	2.5 ± 0.1	–
	2	–	2.8 ± 0.1	–
	3	3.2 ± 0.1	2.6 ± 0.1	4.2 ± 0.2
	4	3.3 ± 0.1	2.6 ± 0.1	4.2 ± 0.2
C	1	3.5 ± 0.1	3.1 ± 0.1	–
	2	3.5 ± 0.1	3.4 ± 0.2	–
	3	3.3 ± 0.1	3.0 ± 0.1	4.5 ± 0.1
	4	3.3 ± 0.1	2.9 ± 0.1	4.3 ± 0.1
D	1	3.4 ± 0.1	2.7 ± 0.1	–
	2	3.4 ± 0.0	2.5 ± 0.1	–
	3	–	2.7 ± 0.1	–
	4	3.3 ± 0.1	2.6 ± 0.1	4.4 ± 0.1
E	1	3.1 ± 0.1	2.5 ± 0.1	–
	2	3.1 ± 0.1	2.5 ± 0.1	–
	3	3.1 ± 0.1	2.5 ± 0.1	–
	4	3.0 ± 0.1	2.3 ± 0.1	3.3 ± 0.1

Table 1. Thickness of the walls of the phantom calculated from CT values using various CT scanners and experiments.

Method of Measurement / Wall	Medial Wall (mm)		Lateral Wall (mm)	
	n	mean ± S.D.	n	mean ± S.D.
Scanner I	40	2.1 ± 0.6	40	2.3 ± 0.7
Scanner III	40	1.8 ± 0.4	40	2.2 ± 0.4
Post-mortem measurement	2	0.6 ± 0.3	4	0.9 ± 0.4

Table 2. A comparison of the thickness of the walls of the maxillary sinuses calculated from the images taken by two CT scanners and by post-mortem measurements.

Method of Measurement	Wall	Left maxillary sinus			Right maxillary sinus	
		lateral wall (mm)	medial wall (mm)	nasal septum (mm)	medial wall (mm)	lateral wall (mm)
CT image of Scanner III		2.0	1.6	1.6	1.6	1.6
CT image of Scanner I		1.6	1.7	1.7	1.7	1.9
CT values of Scanner I		2.4	3.6	3.2	3.0	2.5

Table 3. A comparison of the thickness of the walls of the maxillary sinuses in one case study.

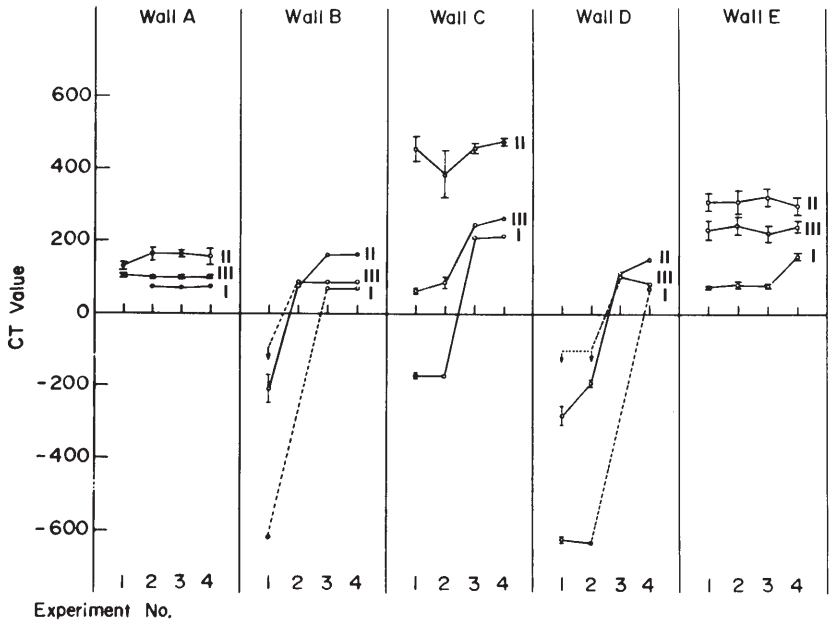

Fig. 8. The average peak X-axis CT values of Walls A to E at the level of the phantom corresponding to the posterior portion of the maxillary sinuses obtained by the three CT scanners.

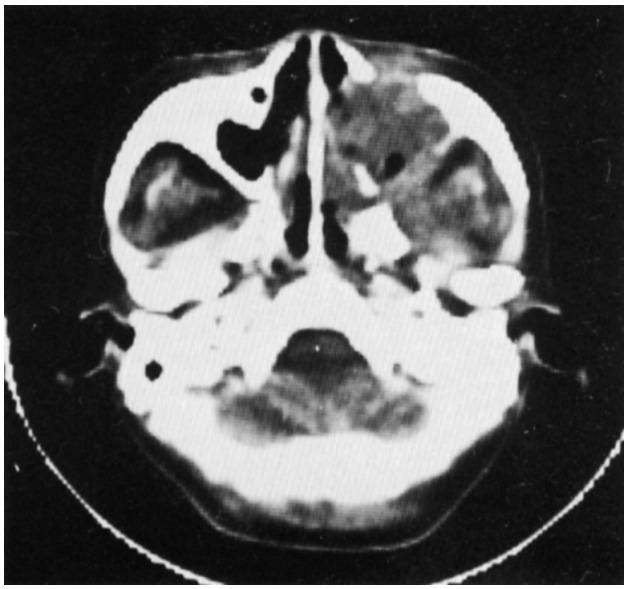

Fig. 9. A 47 year old woman suffering from squamous cell carcinoma of the left maxillary sinus. The CT image taken by Scanner C appeared to have bone defects of the posterior-lateral wall of the left maxillary sinus. Total maxillectomy revealed no bone defects of that wall.

DISCUSSION

There are differences in the scanning modes of the CT scanners used in these experiments. Scanner III is a Translate/Rotate ("Second generation") CT scanner, Scanner II is a Rotate/Rotate ("Third generation") CT scanner, and Scanner I is a Stationary/Rotate ("Fourth generation") CT scanner. The differences in the scanning modes and the systems of image processing affected the results.

The walls made of acrylic plates (1 mm thickness) and aluminum plates (0.1 mm thickness) placed between water and air occasionally did not form any peak CT values because the CT values of the walls were affected by the extremely low (−1000) CT values of air and were drawn down to a zero or minus value ("Undershooting")[10]. These results suggest that thin bony walls placed between water and substances with low CT values such as air and fat may disappear in CT images. Disappearance of thin bony walls may occur more frequently in clinical cases than they did in these experiments because the clinical subjects may not be vertical but oblique to the planes of the scan causing the "partial volume phenomena"[10] to appear. Patient movement may also directly affect CT images.

Extremely thin bony walls such as the posterior-lateral walls of the maxillary sinuses which do not have any real bone defects may occasionally disappear in clinical CT images. This phenomenon was verified in this study. Clinical observations of bony walls surrounding the maxillary sinuses appearing to be thicker in CT images than in vivo was also verified by this study. Bony walls in CT images always appear to be thicker than they actually are, and when their images are visualized by various CT scanners they may appear markedly different. CT

images of patients must always be taken by the same CT scanner under the same scan and display conditions. The walls adjacent to water are shown to be thicker than walls adjacent to air in CT images, and it should be remembered that the walls of the maxillary sinuses involving mucous or tumors appear to be thicker than those adjacent to air in CT images.

CONCLUSION

A phantom simulating the transverse section of the maxillary sinuses was constructed and experimentally imaged by three different CT scanners. The simulated bony walls of the maxillary sinuses were affected by neighboring substances when imaged by CT, occasionally disappeared in the CT images, and did not form any peak CT values. With each CT scanner used in this experiment, the thickness of the walls calculated from CT values was greater than their true thickness. It should be kept in mind that thin bony walls placed between water and air or fat tend to disappear in CT images, and that bony walls appear to be thicker in CT images than in vivo.

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