RESEARCH ARTICLE

Comparison of the accuracy of full head cone beam CT images obtained using a large field of view and stitched images

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Objective: The aim of this study was to investigate the accuracy of the new stitching feature of the Morita 3D Accuitomo device by comparing it with the I-CAT device and real measurements.

Methods: Eight dry skulls were used in this study. The full scan mode of an I-CAT device and the new stitching feature of the Morita 3D Accuitomo device were used to obtain full head cone beam CT (CBCT) images, and the linear distances between the selected anatomical sites were measured by two observers. The real distances were measured directly on the skulls using digital calipers. Statistical analyses were performed using the intraclass correlation coefficient and Bland–Altman Limits of Agreement.

Results: High or perfect agreement was detected between the CBCT images and real measurements. The Bland–Altman Limits of Agreement analysis revealed that the stitched coronal and sagittal images of the Morita might differ by >1.54 – 1.67 or <0.01 mm from the real measurements.

Conclusions: The stitched images of the Morita CBCT device showed perfect agreement with both real measurements and the images of an I-CAT full head scan. After the evaluation of the radiation doses received from stitching sectional images, this device may be used to obtain full head images.

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Introduction

In dentistry, radiographic assessment is one of the most important diagnostic parameters for dental implant planning, orthodontic treatment planning, examination of the maxillofacial region, surgical planning, and pre-endodontic evaluations. This has prompted investigators to compare several imaging methods to determine accurate and effective imaging modalities.¹

Cone beam CT (CBCT) can provide three-dimensional (3D) information of the maxillofacial region; it has gained importance owing to advantages such as a lower radiation dose, faster scan time, lower cost, and

smaller size compared to conventional CT.^{2,3} CBCT systems can be described according to the field of view (FOV) size or scan volume. The dimensions of the FOV or scan volume primarily depend on the detector size and shape, beam projection geometry, and beam collimation. X-ray beam collimation and optimal FOV selection limit radiation exposure to the region of interest. Based on available or multiple scan volumes, the units can be used in the following modes: small, medium, large, or stitched.^{4,5}

Limited or small FOV units are <10 cm size and are appropriate for dentoalveolar imaging and are primarily used in endodontic applications. A medium FOV unit is 10–15 cm in size and is useful for preimplant planning images and pathological conditions in

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the maxillomandibular region. Large FOV units are 15–23 cm in size and are used to diagnose maxillofacial trauma, orthodontic analysis, temporomandibular joint analysis, and various jaw pathologies.⁶

CBCT systems in dental clinics have a limited FOV, which is too small to obtain an image of the entire craniomaxillofacial area. However, large FOV CBCT images are needed for 3D evaluation for orthodontic and orthognathic surgery planning.⁶ To achieve this, it is necessary to enlarge the FOV area of CBCT devices, so a larger detector is needed. However, a large detector is thought to increase radiation exposure, reduce detail, and increase the cost of the device. This suggests that the accuracy of full head images obtained by stitching should be evaluated. Stitching is a 3D acquisition mode that combines two or three small FOV volumes to construct a larger, composite 3D image. The benefits of stitching include a broader range of applications, affordability, flexibility, optimization of the radiation dose for patient safety, and improved workflow.⁷

Only a few studies on stitched CBCT images are available in the literature. The aim of this study was to investigate the accuracy of the new stitching feature of the Morita 3D Accuitomo device by comparing it with the I-CAT device and real measurements.

Methods and materials

This study was approved by the Institutional Review Board of Baskent University (Project no. D-KA 17/08).

Eight dry skulls were used in this study. They were not identified by age, gender, or ethnic background. Full head CBCT images were obtained with the Morita 3D Accuitomo 170® (J Morita, Kyoto, Japan) and I-CAT (Next Generation; Imaging Sciences International, Hatfield, PA) devices. The technical parameters of the Morita CBCT device were 90 kVp, 5 mA, and a 17.5 s exposure time. The largest FOV (170 × 120 mm, 0.250 mm voxel size) was scanned twice: from the base of the mandible to the hard palate and from the hard palate to the vertex, and stitched. For the stitching procedure, the largest FOV should be selected. Firstly, scout image was obtained and then the lower part of the skull was scanned. After, upper part was select the chair goes down in between two exposures. Lastly, software was stitched these two different images.

The technical parameters of the I-CAT device were 120 kVp, 5 mA, and an 8 s exposure time. The FOV was 170 × 230 mm, and the voxel size was 0.250 mm.

The dry skulls were fixed to the CBCT units with a previously prepared plastic device. The mandibles were fixed to the skulls from the temporal region of both sides and from the maxillary anterior region. The Frankfurt line from the centre of the ear through the lowest point of the eye socket was held parallel to the horizontal plane; the sagittal plane of the skull was held parallel to the vertical plane.

Table 1 Definiton of the anatomical landmarks used as references for the measurements

Infraorbital foramen	The lateral border of infraorbital foramen
Anterior nasal spine	Anterior point on maxillary bone
Posterior nasal spine	Posterior limit of bony palate or maxilla
Menton	The most inferior point on the mental symphysis
Pogonion	The most anterior median point on the of the mental symphysis
Nasion	The most anterior median point on the frontonasal suture
1	Infraorbital foramen (R) to infraorbital foramen (L)
2	Anterior nasal spine to posterior nasal spine
3	Infraorbital foramen (R) to menton
4	Infraorbital foramen (L) to menton
5	Infraorbital foramen (R) to pogonion
6	Infraorbital foramen (L) to pogonion
7	Nasion to the deepest point of the nasal cavity base
8	Nasion to menton
9	Nasion to pogonion

Before the study, the main observer discussed with the orthodontist to define which anatomic landmarks would be included. Since our aim was to investigate the accuracy of the stitching images, the anatomical landmarks were selected according to the most distant point from each other. Then, these landmarks were identified on both CBCT images and skull. For calibration, main observer was performed these linear measurements on the CBCT images not included in the study. Selected anatomical sites used in our study are described in Table 1. The linear ($n = 9$) distances between these sites were measured by one observer. All measurements were made by the same observer three times and averaged. The CBCT measurements were performed on the medical monitor (Eizo Radiforce MX270W, EIZO Corporation, Ishikawa, Japan), which is compatible with the i-Dixel (v. 2.2.1.6, J. Morita, Kyoto, Japan) and I-CAT Vision (v. 2.0.2.1, Imaging Sciences International, Hatfield, PA) software programs.

The real distances between the selected sites were measured directly on the dry skulls using high-precision digital calipers (Allendale Electronics Ltd., Hertfordshire, UK) with a measurement range of 0–200 mm (0–8.0 in) and a resolution of 0.015 mm. Figure 1 illustrates the steps of each experiment, including the images obtained from the coronal (Figure 1a) and sagittal (Figure 1b) sections of the CBCT.

Statistical analysis

The agreement among measurements obtained from the stitched and full head CBCT images and the real measurements were assessed using the intraclass correlation coefficient (ICC). According to the ICC, 0.00–0.69

Figure 1 The images obtained from the coronal (a) and sagittal (b) sections of the CBCT. CBCT, cone beam CT.

= unacceptable agreement, 0.70–0.84 = moderate agreement, 0.85–0.94 = high agreement, and 0.95–1.00 = perfect agreement.⁸

In addition, the agreement between the real and CBCT measurements on the stitched Morita 3D Accu-itomo 170[®] images was analysed using the Bland–Altman Limits of Agreement.

Two observers made all measurements to assess interobserver agreement and also to assess intraobserver agreement, the measurements were repeated by the same observer after 2 weeks. Statistical significance was defined as $p < 0.05$.

Results

Intraobserver agreement was perfect for all measurements ($ICC > 0.992$), interobserver agreement was also perfect ($ICC > 0.990$).

The data obtained from the real measurements and the coronal, sagittal, and axial CBCT images of both the Morita and I-CAT devices are presented in Table 2. The agreement among the real measurements and

the Morita and I-CAT CBCT measurements, and the binary comparisons of the coronal, sagittal, and axial sections, are presented in Tables 3 and 4, respectively. The data revealed that the measurements made by both the I-CAT and Morita CBCT devices were very close to the real measurements, and high or perfect agreement was detected between the CBCT and real measurements. In addition, the results of the stitched images of the Morita CBCT device were slightly better than those of the I-CAT device (Tables 3–4).

The Bland–Altman Limits of Agreement analysis revealed that the stitched coronal (Figure 2a,b) and sagittal (Figure 2c,d) images of the Morita might differ by >1.54 – 1.67 mm or <0.01 mm from the real measurements.

Discussion

CBCT for dentistry was introduced in 1988, and it is currently an ideal imaging modality for dental applications such as implantology, surgery, and oral diagnosis. CBCT can be especially useful in situations in which complex treatment planning is required, such as orthognathic surgery. A large FOV and detector are needed for this purpose. These large FOV CBCT systems are not available at every dental clinic owing to their cost and higher radiation dose. Therefore, full head images may be obtained by stitching sectional CBCT images.

3D stitching is a new acquisition mode that combines two or three small FOV volumes for a wider field of examination.⁷ Using this protocol, the FOV can be expanded by extending image capturing while the patient remains motionless. Although this can be accomplished using hardware-based image extension, software-based image registration using visual recognition of specific anatomic features is also possible. This mode can be performed manually by an operator manipulating the images on a computer monitor; semiautomated or automated processes have also been developed.³

Table 2 The data obtained from real measurements as well as the coronal, sagittal and axial CBCT images of the both Morita and I-CAT devices (n:8)

Anatomical sites	Real (mm)	Morita (mm)			I-CAT (mm)		
	Mean $\pm$ SD	Coronal	Sagittal	Axial	Coronal	Sagittal	Axial
		Mean $\pm$ SD	Mean $\pm$ SD	Mean $\pm$ SD	Mean $\pm$ SD	Mean $\pm$ SD	Mean $\pm$ SD
1	56.92 $\pm$ 4.07	57.32 $\pm$ 4.42	–	57.39 $\pm$ 1.50	57.43 $\pm$ 4.20	–	57.24 $\pm$ 1.45
2	51.18 $\pm$ 3.38	–	51.69 $\pm$ 1.14	51.76 $\pm$ 3.16	–	51.47 $\pm$ 1.16	51.59 $\pm$ 3.25
3	79.42 $\pm$ 4.41	80.18 $\pm$ 3.88	80.07 $\pm$ 1.39	–	79.91 $\pm$ 4.53	79.78 $\pm$ 1.57	–
4	80.78 $\pm$ 2.43	81.64 $\pm$ 2.25	81.48 $\pm$ 0.78	–	81.24 $\pm$ 2.33	81.38 $\pm$ 0.97	–
5	73.70 $\pm$ 3.27	74.69 $\pm$ 2.82	74.51 $\pm$ 1.00	–	74.32 $\pm$ 3.55	74.22 $\pm$ 1.22	–
6	74.40 $\pm$ 2.82	75.26 $\pm$ 2.61	75.10 $\pm$ 0.93	–	74.82 $\pm$ 2.81	74.61 $\pm$ 0.96	–
7	53.08 $\pm$ 1.95	53.71 $\pm$ 2.15	53.59 $\pm$ 0.76	–	53.46 $\pm$ 1.90	53.44 $\pm$ 0.62	–
8	110.86 $\pm$ 4.85	111.93 $\pm$ 4.26	111.80 $\pm$ 1.50	–	111.41 $\pm$ 4.75	111.14 $\pm$ 1.67	–
9	103.04 $\pm$ 4.87	104.31 $\pm$ 4.27	104.16 $\pm$ 1.54	–	103.46 $\pm$ 4.68	103.53 $\pm$ 1.76	–

CBCT, cone beam CT; SD, standard deviation.

Table 3 The agreement among the real measurements, both Morita and I-CAT CBCT measurements; and also binary comparisons on coronal and axial sections

Anatomical sites	Agreement among real and both CBCT measurements	95% confidence interval		Binary comparisons	ICC	95% confidence interval	
	ICC	Lower border	Upper border			Lower border	Upper border
1	0.984	0.948	0.997	Real-I-CAT	0.979	0.905	0.996
				Real-Morita	0.989	0.725	0.998
				I-CAT-Morita	0.985	0.930	0.997
2	0.981	0.922	0.996	Real-I-CAT	0.977	0.559	0.996
				Real-Morita	0.985	0.862	0.997
				I-CAT-Morita	0.981	0.917	0.996
3	0.984	0.925	0.997	Real-I-CAT	0.973	0.622	0.995
				Real-Morita	0.992	0.596	0.999
				I-CAT-Morita	0.984	0.931	0.997
4	0.949	0.703	0.990	Real-I-CAT	0.913	0.065	0.986
				Real-Morita	0.978	0.242	0.997
				I-CAT-Morita	0.958	0.764	0.992
5	0.954	0.799	0.990	Real-I-CAT	0.932	0.119	0.989
				Real-Morita	0.973	0.622	0.996
				I-CAT-Morita	0.952	0.801	0.990
6	0.958	0.790	0.992	Real-I-CAT	0.928	0.214	0.988
				Real-Morita	0.988	0.174	0.998
				I-CAT-Morita	0.55	0.785	0.991
7	0.963	0.756	0.993	Real-I-CAT	0.943	0.064	0.992
				Real-Morita	0.975	0.372	0.996
				I-CAT-Morita	0.974	0.862	0.995
8	0.978	0.870	0.996	Real-I-CAT	0.959	0.419	0.993
				Real-Morita	0.993	0.251	0.999
				I-CAT-Morita	0.983	0.891	0.997
9	0.965	0.822	0.993	Real-I-CAT	0.939	0.347	0.990
				Real-Morita	0.994	0.841	0.999
				I-CAT-Morita	0.960	0.710	0.993

CBCT, cone beam CT; ICC, intraclass correlation coefficient.

In the literature, only three investigations have assessed the accuracy of full head CBCT images obtained by stitching.^{3,7,9} Egbert et al.⁷ studied the accuracy and reliability of stitched CBCT images. They concluded that although differences between the real measurements and stitched images may allow the fabrication of image-guided implant surgical stents, the differences must be considered for the diagnosis and treatment planning of both surgical and non-surgical dental procedures. Kim et al.³ found no significant differences between the gold-standard and manually-merged CBCT images, but found significant differences between the gold-standard and software-aligned CBCT images.

Our study used eight dry skulls; the distances between the selected anatomical sites were measured on CBCT images and compared to the real measurements. To simulate the clinical conditions and avoid metal artefacts, no markers were used on the dry skulls. Other studies frequently used plastic or dry skulls, and the reference points were marked with gutta-percha or metal objects.^{10–12}

There are many studies related to the accuracy of linear measurements on CBCT images.^{10–12} Most of these were performed using different CBCT devices. The effects of changes in head position were also assessed. These studies concluded that linear and horizontal measurements were highly accurate, with no difference between compared devices.^{10,13–15} While a few studies found that changes in head position did not affect accuracy,^{13,15} one study showed that different head positions did affect the measurements.¹⁶

In the literature, influence of patient motion on quality of CBCT scan and dimensional stability was also assessed.^{17–22} These studies suggested that patient movement usually presents itself in CBCT images and prevalence of movement was approximately 20% of the cases.¹⁷ Therefore, movement artefacts is not only seen in the stitched images, but also can be determined in each CBCT images. To overcome the movement or motion artefacts, using two or three marks, automated detection concept or correction algorithms have been suggested.^{18,19,21} Studies regarding the effect of patient

Table 4 The agreement among the real measurements, both Morita and I-CAT CBCT measurements; and also binary comparisons on sagittal and axial sections

<i>Anatomical sites</i>	<i>Agreement among real and both CBCT measurements</i>	<i>95% confidence interval</i>		<i>Binary comparisons</i>	<i>ICC</i>	<i>95% confidence interval</i>	
	<i>ICC</i>	<i>Lower border</i>	<i>Upper border</i>			<i>Lower border</i>	<i>Upper border</i>
1	0.992	0.966	0.998	Real-I-CAT	0.987	0.878	0.998
				Real-Morita	0.996	0.620	1.000
				I-CAT-Morita	0.992	0.965	0.998
2	0.982	0.937	0.996	Real-I-CAT	0.982	0.635	0.997
				Real-Morita	0.988	0.934	0.998
				I-CAT-Morita	0.977	0.901	0.995
3	0.987	0.945	0.997	Real-I-CAT	0.979	0.722	0.996
				Real-Morita	0.996	0.694	0.999
				I-CAT-Morita	0.986	0.938	0.997
4	0.947	0.801	0.989	Real-I-CAT	0.936	0.232	0.990
				Real-Morita	0.959	0.439	0.993
				I-CAT-Morita	0.941	0.739	0.988
5	0.963	0.853	0.992	Real-I-CAT	0.949	0.306	0.992
				Real-Morita	0.979	0.754	0.996
				I-CAT-Morita	0.960	0.832	0.992
6	0.967	0.848	0.993	Real-I-CAT	0.947	0.433	0.991
				Real-Morita	0.996	0.888	0.999
				I-CAT-Morita	0.959	0.749	0.992
7	0.954	0.836	0.990	Real-I-CAT	0.957	0.306	0.993
				Real-Morita	0.959	0.711	0.992
				I-CAT-Morita	0.945	0.766	0.989
8	0.978	0.901	0.995	Real-I-CAT	0.959	0.649	0.993
				Real-Morita	0.997	0.955	0.999
				I-CAT-Morita	0.976	0.826	0.995
9	0.970	0.874	0.994	Real-I-CAT	0.951	0.482	0.992
				Real-Morita	0.993	0.773	0.999
				I-CAT-Morita	0.962	0.830	0.992

CBCT, cone beam CT; ICC, intraclass correlation coefficient.

motion on quality of stitched CBCT images concluded that measurements based on stitching images are accurate and small variations in the patient's head position do not influence the measurement accuracy.²²

Our study data revealed that the measurements made by both the I-CAT and Morita CBCT devices were very close to the real measurements, and high or perfect agreement was observed between measurements from CBCT images and real measurements. It was also determined that the results of the stitched images from the Morita CBCT device were slightly better than images from the I-CAT device. As a result, it may be possible that the new stitching feature of the Morita CBCT device can be used safely to obtain full head images.

It is not recommended to use CBCT routinely for every patient. In 2008, the Executive Council of the American Academy of Oral and Maxillofacial Radiology published an executive opinion statement on the performance and interpretation of CBCT in dentistry. The Executive Council proposed guidelines and principles for CBCT use in contemporary dental

practice including practitioner responsibilities, documentation requirements, optimization of the radiation dose, and quality assurance. If CBCT is used, the benefits to the patient must outweigh the risks associated with exposure to ionizing radiation, as with any radiographic imaging technology.²³ The British Orthodontic Society Guidelines state that "Radiographs should only be justified when the management of patient is dependent on the information obtained".²⁴ According to the 2007 recommendations of the International Commission on Radiological Protection Publication 103 for calculation of the effective dose, the three routinely used radiographic modalities in orthodontics include lateral cephalometry, posteroanterior graphy, and panoramic radiography, with a collective effective dose of 25–35 μ Sv. The effective dose of CBCT with a large FOV used for orthodontic diagnosis is 68–1073 μ Sv, which is several times higher.¹⁶ Ludlow et al reported that the adult effective dose for any protocol was 46–1073 μ Sv for large FOVs, 9–560 μ Sv for medium FOVs, and 5–652 μ Sv for small FOVs. The paediatric effective dose of any

Figure 2 Bland–Altman plot of the measurements of the stitched coronal (a, b) and sagittal (c, d) images of the Morita CBCT device. CBCT, cone beam CT; ICC, intraclass correlation coefficient.

protocol was 13–769 μSv for large or medium FOVs and 5–582 μSv for small FOVs.²⁵ In light of this information, its use is currently recommended in cases in which clinical examination supplemented with conventional radiography cannot supply satisfactory diagnostic information.²⁶

It is well-known that CBCT protocol should be optimized according to the clinical indication in terms of kVp, mA, exposure time and FOV. CBCT equipment should offer a choice of volume sizes. The effective dose for different CBCT devices shows a distinction between small-, medium-, and large-FOV CBCT scanners.^{27,28}

The range of doses between the devices is too large to consider them as a single modality; even though the geometry of the image acquisition is basically the same, the differences in collimation of the cone beam, as well as the X-ray exposure factors, lead to considerable differences in absorbed dose for all organs in the head and neck region.²⁸ Studies comparing the effective doses for different CBCT scanners, the highest radiation dose

is measured for the largest protocols. This extra volume represents an extra radiation dose. Therefore, dimension of the FOV is one of the known factor influencing effective dose. If all other factors affecting the dose remain constant, a larger FOV results in a higher dose.^{28–30}

A potential limitation of this study is not to mimic clinical situation completely due to experimental nature. However, to achieve the most accurate clinical measurement with the least radiation dose, these experimental studies should be performed. In light of these studies, clinical use of the stitched images can be suggested.

In conclusion, the stitched images obtained using the Morita CBCT device showed perfect agreement with both real measurements and the full head scan from the I-CAT device, but little information is available regarding the radiation dose of stitched sectional images. Therefore, it is necessary to evaluate the radiation doses received from stitching sectional images compared to those from large scan volume images for clinical use.

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