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An in vitro comparison of subjective image quality of panoramic views acquired via 2D or 3D imaging

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Abstract

Objectives The objective of this study is to compare subjective image quality and diagnostic validity of cone-beam CT (CBCT) panoramic reformatting with digital panoramic radiographs.

Materials and methods Four dry human skulls and two formalin-fixed human heads were scanned using nine different CBCTs, one multi-slice CT (MSCT) and one standard digital panoramic device. Panoramic views were generated from CBCTs in four slice thicknesses. Seven observers

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G. Kalema I-BIOSTAT, Katholieke Universiteit Leuven, Leuven, Belgium scored image quality and visibility of 14 anatomical structures. Four observers repeated the observation after 4 weeks. *Results* Digital panoramic radiographs showed significantly better visualization of anatomical structures except for the condyle. Statistical analysis of image quality showed that the 3D imaging modalities (CBCTs and MSCT) were 7.3 times more likely to receive poor scores than the 2D modality. Yet, image quality from NewTom VGi[®] and 3D Accuitomo 170[®] was almost equivalent to that of digital panoramic radiographs with respective odds ratio estimates of 1.2 and 1.6 at 95% Wald confidence limits. A substantial overall agreement amongst observers was found. Intraobserver agreement was moderate to substantial.

Conclusions While 2D-panoramic images are significantly better for subjective diagnosis, 2/3 of the 3D-reformatted panoramic images are moderate or good for diagnostic purposes.

Clinical relevance Panoramic reformattings from particular CBCTs are comparable to digital panoramic images concerning the overall image quality and visualization of anatomical structures. This clinically implies that a 3D-derived panoramic view can be generated for diagnosis with a recommended 20-mm slice thickness, if CBCT data is a priori available for other purposes.

Keywords Cone-beam computed tomography · Diagnostic imaging · Image quality · Panoramic radiography · Computerassisted image interpretation

Introduction

Panoramic radiography has been used in dentistry for more than half a century [1-3]. It has been widely used for screening purposes, periodontal evaluation, orthodontic

treatment planning, oral surgery and also for implant treatment planning. It is considered as a very important diagnostic tool in dentistry. Even though it has been widely accepted, it still carries several down sides such as geometric distortion and superimposition of structures [4-7].

Three-dimensional images started to play an important role in oral diagnosis. First, computed tomography (CT) was introduced to the dental field in 1990s. However, because of its high radiation dose, it was not broadly used. In 1996, the first dental cone-beam computed tomography (CBCT) was invented and the technology has been developing since. Nowadays, there are more than 30 CBCTs available on the market and their function has been developed to serve dentists' objectives. In many machines, it is possible to choose different field of views (FOV) and different resolution parameters depending on the clinical indication for producing the images. Software tools accompanying the CBCTs allow clinicians to display the 3D data in clinically suitable views, e.g., cross-sectional slices and panoramic view. Some software programs even allow 3D cephalometric analysis [8, 9]. Some clinicians still refer patients for additional conventional digital panoramic radiographs and conventional lateral cephalograms despite the fact that CBCT data has already been acquired. If the panoramic images generated from three-dimensional data have equal diagnostic quality as conventional digital panoramic radiographs, then it is not necessary for clinicians to take extra conventional 2D radiographs. Patients' datasets will be more compact and the radiation dose to patients can be reduced. However, there is only little evidence that can prove if the panoramic images generated from threedimensional data (CT or CBCT) have equal diagnostic quality as conventional digital panoramic radiographs [10–12].

The aims of this study were to compare the diagnostic validity of the panoramic view derived from different CBCTs and a multi-slice CT (MSCT) with the standard digital panoramic radiograph. The latter is meant to evaluate whether CBCT derived panoramic views could avoid making another panoramic radiograph if a CBCT is a priori available. During this particular study, inter- and intraobserver variabilities were also assessed.

Materials and methods

The samples consisted of four dry human skulls and two formalin-fixed human heads obtained from the collection of the Oral Imaging Center, Katholieke Universiteit Leuven. The mandibles were fixed to the skulls at the maximum occlusion by using broad tape attached from the temporal bone, crossing the inferior border of the mandible to the temporal bone of the opposite side.

Image acquisition

To acquire conventional digital panoramic images, the dry skulls were put in a plastic bucket filled with water to simulate the attenuation of soft tissue. Additional cervical spines were placed below the foramen magnum to resemble a real human cervical. The two formalin-fixed heads were put in plastic bags with additional cervical spines attached at the postero-inferior side of the bags.

The samples were put in a standard digital panoramic device (Veraviewepocs 2D[®], J. Morita, Kyoto, Japan) with CCD sensor. The Frankfurt horizontal plane, midline and the canine indication line were adjusted as in patients. The "standard adult" panoramic setting was selected (64 kVp, 8.9 mA 7.4 s, with pixel size 0.144 mm). All panoramic radiographs were exported as TIFF files.

The samples were also placed in a MSCT (SOMATOM[®] Sensation 64, Siemens, Erlangen, Germany) at the Department of Radiology, University Hospital Leuven, Gasthuisberg, Leuven, Belgium. The samples were placed horizontally and dry skulls were put in a different polystyrene box to be able to place the skulls horizontally with water as soft tissue simulation. Standard parameters for head and neck area were used (120 kVp, 250 mAs, voxel size 0.43 mm). The datasets were exported as Digital Imaging and Communications in Medicine (DICOM) files.

Images were taken on the samples by nine different conebeam CT (CBCT) machines as shown in Table 1. The large maxillofacial FOV was selected for each machine to ensure that all anatomical structures mandatory for panoramic viewing were covered. All data were exported as DICOM files.

Panoramic image generation

All DICOM data from MSCT and CBCTs were imported in OnDemand3D[®] software, version 1.0.8.0408 (Cybermed, Seoul, Republic of South Korea). Before generating a panoramic view, the skull position was adjusted for standardization. First, the Frankfurt horizontal was checked and adjusted to be parallel with the horizontal plane. The midline of the face was adjusted to be perpendicular to the horizontal plane. From the axial view of alveolar process of the mandible (mid-root area), a curve was drawn manually starting 1 cm posterior from the most posterior border of ramus to cover the condyle in the slice. Four points were marked bilaterally within the path on each side of the jaw and one at the midline (most posterior, molar, premolar, canine and one at midline; Fig. 1). The curves were checked to ensure that all anatomical points of interest of both maxilla and mandible covered. After the panoramic curves were confirmed, panoramic images were generated in different slice thicknesses: 10, 15, 20, 25 mm and then saved in

Table 1 Technical parameters of CBCT devices

CBCT	Manufacturer	FOV (cm) (D×H)	Voxel size (mm)	Voltage (kV)	mAs
3D Accuitomo 170	J. Morita, Kyoto, Japan	17×12	0.25	90	154
Galileos Comfort	Sirona Dental Systems, Bensheim, Germany	15×15	0.29	85	21
i-CAT Next Gen	Imaging Sciences International, Hatfield, PA, USA	23×17	0.30	120	35
Iluma Elite	Imtec (3 M), Ardmore, OK, USA	21×14	0.19	120	152
Kodak 9500	Kodak Dental Systems, Carestream Health, Rochester, NY, USA	20×18	0.30	90	108
NewTom VGi	Quantitative Radiology, Verona, Italy	15×15	0.30	110	122 ^b
Picasso Trio ^a	VATECH, Yongin, Republic of Korea	12×7	0.20	85	90
Scanora 3D	Soredex, Tuusula, Finland	14.5×13	0.25	90	48
SkyView	MyRay, Celfa Dental Group, Imola, Italy	17×17	0.34	90	51.5

^a Picasso Trio® was the largest FOV from VATECH available in Europe at the time of scanning

^b Mean exposure of six samples. The device uses automatic exposure based on density distribution of scout image

TIF format (Fig. 2). This process was performed by a 5-year-experienced dentomaxillofacial radiologist.

Observation scoring technique

Seven observers were initially introduced to an instruction session in observation and scoring of panoramic images prior to the first observation. The observation was performed under standardized conditions: dimmed ambient light, with 20-in. clinical review display (MDRC-2120, Barco N.V., Kortrijk, Belgium). Digital panoramic radiographs and panoramic images generated from 3D data were randomized. Seven observers performed the observation on 238 images in total. Observers had to give scores for overall image quality and visibility of 14 anatomical landmarks: 5 in the maxilla and 9 in the mandible. The description of each score is shown in Table 2. Four observers repeated the observation after a 4-weeks interval.

Statistical analysis

Statistical analysis was performed with SAS software (Statistical Analysis System Version 9.2, SAS Institute Inc,

Fig. 1 Panoramic reformatting arch, drawn on the axial view of each CBCT scan. The sketch figure on the *right* indicates the marking of the different curve points during the drawing process. A total of nine points were marked for one panoramic curve Cary, NC). The data was analysed while taking into account the ordering in the scores using ordinal logistic regression (OLR). OLR fits, in essence, a binary logistic regression model for each cumulative logit; therefore, odds ratios can be used for interpretation purposes [13]. Intra-observer and inter-observer variability were assessed by Kappa statistics. Overall agreement was assessed using Kendall's coefficient of concordance for ordinal response.

Results

A total of 238 images were observed and scored. Substantial agreement was found for all observers at 0.63 of Kendall's coefficient of concordance. Intra-observer variability of each observer ranged from moderate to substantial (weighted Kappa 0.46–0.74). Inter-observer variability of each observer pair ranged from fair to substantial (weighted Kappa 0.32–0.62) [14].

Overall image quality

The frequency of scores for different devices, scored by all seven observers is shown in Table 3. The most common







Fig. 2 Panoramic images generated from NewTom VGi[®] by OnDemand3D[®] with different slice thicknesses (**a** 10 mm, **b** 15 mm, **c** 20 mm, **d** 25 mm)

reason for the image error in both 2D and 3D imaging modalities as given by the observers is image blurring.

An ordinal logistic regression model was fitted to this study and the results were presented in a form of odds ratio estimates with 95% Wald confidence limits. It was found that when comparing the 2D (Veraviewepocs 2D[®]) with the 3D (all CBCTs and the MSCT), the 3D modalities had 7.25 times more chance to receive poor score (Table 4).

Anatomical structures

Conventional panoramic radiograph showed superiority over panoramic imaging derived from 3D dataset except for the visualization of the condyle. Figure 3 shows the odds ratio estimates of different structures at 95% Wald confidence limits tested in this study. Maxillary structures yielded higher odds ratio estimates, which mean that the maxillary structures in the 3D modality were more likely to receive poor scores than the 2D images. The visualization of mandibular structures was, however, found to be almost equal to the conventional panoramic radiography (except for periodontal structure and anterior/posterior teeth sextant).

Devices

The SkyView[®] machine received a 99.4% poor score. Therefore, it was left out from the comparison of all devices for computational reasons. When comparing the performance of different 3D devices to the standard panoramic machine, it was found that the quality of the images from NewTom VGi[®] and 3D Accuitomo 170[®] was almost equivalent to the images taken by conventional digital panoramic machine with odds ratio estimates of 1.2 and 1.6,

Table 2 Scoring technique

			Description
Overall image quality	Score	1	Very poor (no diagnosis possible)
		2	Poor (diagnosis probably possible)
		3	Acceptable (diagnosis possible)
		4	Very good (diagnosis definitely possible)
Visibility of anatomical structures Maxillary structures	Score	1	Significant structure not visible, no diagnosis possible
Lower and anterior border of maxillary sinus		2	Only broad details seen, diagnosis doubtful
Pterygomaxillary fissure/posterior border of maxillary sinus		3	Small details visualized, diagnosis probably possible
Periodontal structures (alveolar process and supporting structures)		4	Fine details visualized, diagnosis definitely possible
Anterior sextant/anterior teeth			
Posterior sextant/posterior teeth Mandibular structures	Possible reasons for error	0	No reason
Condylar process (TMJ) Coronoid process		1	Density/brightness/contrast is not optimal
Ramus Body and angle of mandible		2	Blurring/Unsharpness
Mandibular canal Mental foramen		3	Overlapping/superimposition of structures
Periodontal structures (alveolar process and supporting structures)		4	Area of interest is not included in the image
Anterior sextant/anterior teeth			-
Posterior sextant/posterior teeth		5	Other than above

Overall image quality	Devices											
Frequency	Veraview epocs 2D	3D Accuitomo 170	Galileos Comfort	i-CAT Next Gen	Iluma Elite	Kodak 9500	NewTom VGi	Picasso Trio	Scanora 3D	Skyview	MSCT	Total
Poor ^a	8	23	89	106	86	64	17	53	51	167	112	776
Acceptable	12	84	68	62	76	98	79	48	110	1	52	069
Good	22	61	11	0	9	6	72	11	7	0	4	200
Total	42 ^b	168	168	168	168	168	168	112 ^c	168	168	168	1,666 ^d
^a The scores "very pc	oor" and "poor" were	collapsed into one s	core (poor) for con	nputational reasor	IS							
^b No different slice th	hickness for Veraview	epocs 2D [®] : 6 samp	$s \times 7$ observers=4	5								
^c Images of four sam	ples were taken by Pi	casso Trio® : 4 sam	ples×4 slice thickn	esses×7 observer	s = 112							
^d Total 238 images w	vere scored, therefore	the total frequency=	$238 \times 7 = 1,666$									

rable 3 Frequency table of scores for overall image quality by seven observers

respectively. In contrast, MSCT is performing much worse, being 29.7 times more likely to receive poor image quality score than conventional digital panoramic machine (Fig. 4).

Slice thickness

Conventional digital panoramic radiographs showed significantly superior quality than all different slice thicknesses of the panoramic derived from CBCT and MSCT. Among different slice thicknesses, it was found that 20 mm is slightly better than other slice thickness settings (Point estimate at 6.56 compared to the conventional panoramic radiograph), followed by 15 mm (6.90), 10 mm (7.54) and 25 mm (8.17) consecutively.

Discussion

Panoramic view can be easily generated from 3D datasets. The scoring system used in this research was based on Gijbels' study published in 2000 [15], comparing image quality of direct digital and conventional panoramic radiographs. Fourteen anatomical landmarks were added in the protocol to be able to evaluate their visualization as this is very crucial for panoramic radiographic diagnosis. We found that the intraand inter-observer agreement ranged from fair to good which proved that the methods were statistically valid.

The image quality assessment in this study is based on a subjective rating as there is no reference standard. The metal artifact assessment was not the main aim of this study; therefore, it was not evaluated separately from the overall image quality. It should also be noted that the nine included CBCT devices were compared at the level of the DICOM dataset, not using the systems' own software. One image viewing software (OnDemand3D[®]) was used to allow for a standardized evaluation.

Our sample size of four dry skulls and two formalin heads was rather small but to acquire images of skulls samples from different CBCT devices in different locations was a demanding task. The results of this in vitro study showed that conventional digital panoramic radiographs are significantly better both in overall image quality and visualization of anatomical structures.

Differences in the quality could be caused by differences in nature of the image. Conventional digital panoramic radiograph has much higher spatial resolution than both CBCTs and the medical CT. This could explain why the overall image quality of conventional digital panoramic radiograph is approximately seven times better. Furthermore, it could explain why image blurring was the most common reason for error. Indeed, as the spatial resolution for CBCT and CT images is limited, the sharpness will not be as high compared to panoramic radiographs. All CBCTs

	Odds ratio estimates			
Effect	Point estimate	95% Wald	confidence limits	
3D modality vs 2D modality	7.25	4.01	13.12	

 Table 4 Overall image quality of 2D modality versus 3D modality

except SkyView[®] performed better than the medical CT, confirming the effect of spatial resolution.

The visualization of mandibular structures was slightly better than maxillary structures. The reason might be that the nature of most mandibular structures is well corticated and formed by denser bone than in the maxilla; therefore, even if the contrast and sharpness of the images were limited, the landmarks were clear enough to be used for diagnosis.

For the 3D reformatted panoramic images, the minimum slice thickness (i.e. 0.2 mm) was not included in this protocol, although it may provide less blurring and improve contrast; however, it will not allow us to visualize all the teeth and other important anatomical structures. In order to cover all anatomical structures necessary for panoramic images, four slice thicknesses were selected for this study. It appeared that 20 mm thickness was slightly better than the others.

There are only a few studies that compared conventional panoramic radiographs with panoramic reformattings derived from 3D data. Pawelsik et al. [10] compared conventional panoramic radiographs with panoramic and cross-sectional images reconstructed from the NewTom-9000[®] (Quantitative Radiology, Verona, Italy) in diagnosis of relationship between third molars and mandibular canals. The authors reported that the cross-sectional images had given significantly clearer perception of the mandibular nerve than the conventional panoramic radiographs although the scores of conventional panoramic images were significantly better than the reconstructed panoramic images [10]. The results of

the present study agree with previous results. CBCTs have been developed in the past decade; however, the resolution of conventional panoramic radiographs is still significantly superior. Nevertheless, CBCT can provide 3D views of the jaw and is useful to locate the mandibular canal in the crosssectional slices.

Mischkowski et al. compared reconstructed panoramic images acquired from Galileos® (Sirona Dental Systems, Bensheim, Germany) with conventional panoramic radiographs [11]. It was found that there was no significant difference in diagnostic quality between both image modalities. Image quality of reconstructed panoramic views was significantly lower than the conventional panoramic radiographs but anatomical structures except mandibular canal and alveolar ridge gingiva were better visualized in the panoramic view from CBCT. The authors concluded that the reconstructed panoramic views from CBCT were better in diagnosis of specific lesions, whereas conventional panoramic radiographs provided better image quality for a general overview. The diagnostic quality is equal for both modalities [11]. This is in agreement with the present study. The image quality of conventional panoramic radiographs is higher but for the visualization of anatomical structures, the opposite results were found. This can be explained by differences in "Materials and methods". In Mischkowski's study, the reconstructed panoramic images were viewed in the Galileos software and the inspection window was used. This inspection window may have provided more visualization to specific structures and then resulted in higher scores for the anatomical landmarks. In our study, only the condyle did not show significant difference between the two imaging modalities although the image quality of some of the mandibular structures (ramus, body and angle of mandible, mandibular foramen and mandibular canal) of the 3D derived images were almost equal to the 2D system. The other reason can be that in this study, as nine CBCTs and

Fig. 3 Odds ratio estimates with 95% Wald confidence limits of different anatomical structures in panoramic images generated from 3D data. The closer the odds ratio estimates to 1, the closer the visualization as compared to the panoramic radiograph from conventional 2D modality. Larger odd ratios correspond to greater differences between 2D and 3D for the visualization of this structure



Anatomical structures

Fig. 4 Odds ratio estimates with 95% Wald confidence limits of different devices. The baseline corresponds with the Veraviewepocs 2D[®]. The closer the odds ratio estimates to 1, the closer the quality as compared to the panoramic radiograph from conventional 2D modality



one MSCT were tested, there could then be more variability among these devices.

In 2008, Angelopoulos et al. [12] published a study comparing digital panoramic radiography and CBCT for the identification of mandibular canals. The results showed that panoramic images generated from CBCT were significantly better than digital panoramic radiographs in identifying the mandibular canals [12]. This result is not in agreement with the results of the present study. The reason could be the difference in CBCT devices used in the study as well as the slice thickness. Angelopulos and coworkers [12] used 5.2-mm slice thickness which is thinner than that in our study. At this thickness, the images may be able to cover the area of mandibular canals and avoided other structures from superimposing with the canals. Instead we used 10, 15, 20 and 25 mm. This factor might affect the visibility of the mandibular canals, but the increased slice thickness could cover and show more structures both in the maxilla and the mandible.

There are two studies that were performed on the accuracy of measurements on CBCT derived panoramic images. Ludlow et al. compared measurements of mandibular anatomy on panoramic reconstructions from CBCT (2D) and on axial slices (3D) with the physical measurements [16]. It was found that both 2D and 3D techniques provided acceptably accurate measurements of mandibular anatomy [16]. In 2010, Van Elslande et al. reported results of the accuracy of mesio-distal root angulation projected by panoramic reconstructed from CBCT. They concluded that panoramic reconstructions on CBCT were more accurate than conventional panoramic radiography concerning mesio-distal root angulation [17]. Although in the present study, measurements were not done, these two references suggested that panoramic images derived from CBCT allowed suitably accurate measurement results which are useful for orthodontic and implant treatment planning.

Radiation exposure of the cone-beam CT is still a big concern in dental field. A new report on radiation dose of different CBCT devices has been published by Pauwels et al. [18]. The results showed that the dose received is strongly related to FOV size and also dependent on the exposure parameter. In order to gain full panoramic images, a medium to big FOV should be used; but it must be kept in mind that, at this stage, CBCT still cannot replace the use of conventional panoramic radiographs. However, if there is a diagnostic requirement for CBCT, for some devices, moderate to good quality panoramic images can be generated from existing CBCT data.

Conclusion

While 2D panoramic images are still significantly better, 2/3 of the 3D-derived panoramic images, depending on the machines, are moderate to good concerning subjective diagnosis. Furthermore, panoramic images generated from some cone-beam CT devices seem to be comparable to the conventional digital panoramic images concerning the overall subjective image quality and visualization of anatomical structures. On 3D-derived panoramics, mandibular structures tended to be more visible than the maxillary structures and 20-mm slice thickness is recommended.

The radiation dose to patients must be concerned. Conventional digital panoramic radiographs must not be replaced by CBCT images, but CBCT should be taken only if there is a clear indication.

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Conflict of interest The authors declare that they have no conflict of interest.

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