RESEARCH ARTICLE

Spatial resolution measurements by Radia diagnostic software with SEDENTEXCT image quality phantom in cone beam CT for dental use

Hiroshi Watanabe, Yoshikazu Nomura, Ami Kuribayashi and Tohru Kurabayashi

Department of Oral and Maxillofacial Radiology, Graduate School, Tokyo Medical and Dental University, Tokyo, Japan

Objectives: We aimed to employ the Radia diagnostic software with the safety and efficacy of a new emerging dental X-ray modality (SEDENTEXCT) image quality (IQ) phantom in CT, and to evaluate its validity.

Methods: The SEDENTEXCT IQ phantom and Radia diagnostic software were employed. The phantom was scanned using one medical full-body CT and two dentomaxillofacial cone beam CTs. The obtained images were imported to the Radia software, and the spatial resolution outputs were evaluated. The oversampling method was employed using our original wire phantom as a reference. The resultant modulation transfer function (MTF) curves were compared. The null hypothesis was that MTF curves generated using both methods would be in agreement. One-way analysis of variance tests were applied to the f50 and f10 values from the MTF curves. The f10 values were subjectively confirmed by observing the line pair modules.

Results: The Radia software reported the MTF curves on the *xy*-plane of the CT scans, but could not return f50 and f10 values on the *z*-axis. The null hypothesis concerning the reported MTF curves on the *xy*-plane was rejected. There were significant differences between the results of the Radia software and our reference method, except for f10 values in CS9300. These findings were consistent with our line pair observations.

Conclusions: We evaluated the validity of the Radia software with the SEDENTEXCT IQ phantom. The data provided were semi-automatic, albeit with problems and statistically different from our reference. We hope the manufacturer will overcome these limitations.

Dentomaxillofacial Radiology (2018) 47, 20170307. doi: [10.1259/dmfr.20170307](https://doi.org/10.1259/dmfr.20170307)

Cite this article as: Watanabe H, Nomura Y, Kuribayashi A, Kurabayashi T. Spatial resolution measurements by Radia diagnostic software with SEDENTEXCT image quality phantom in cone beam CT for dental use. *Dentomaxillofac Radiol* 2018; 47: 20170307.

Keywords: computed tomography; quality assurance; spatial resolution; modulation transfer function; comparative study

Introduction

Cone beam CT (CBCT) for dental and maxillofacial use is frequently and widely used in dental practice.¹ There are many types of CBCT that have been developed and are in the market; however, a standardized quality assurance (QA) program for them has not yet been established and universally accepted

and adopted. In Europe, the safety and efficacy of a new emerging dental X-ray modality (SEDENTEXCT) project provided the QA process for CBCT in 2012.² The SEDENTEXCT Consortium also developed a SEDENTEXCT image quality (IQ) phantom³ (Leeds Test Objects Ltd., North Yorkshire, UK) (Figure 1) and an analysis-automated software, Radia diagnostic (Radiological Imaging Technology, Inc., Colorado Springs, CO). A SEDENTEXCT IQ phantom is frequently employed for evaluating CBCT

Correspondence to: Dr Hiroshi Watanabe, E-mail: hiro.orad@tmd.ac.jp

Received 05 August 2017; revised 22 September 2017; accepted 07 November 2017

Figure 1 SEDENTEXCT image quality phantom (a). The appearance of the phantom and the lid. (b). The left image shows a sectional view at the section of 4 of the phantom using the Radia software, and the right drawing explains the insert modules. The modules of ①, ②, ③ and ④ were an edge for a line spread function, a 0.25 μm wire for a point spread function, line pairs on the xy -plane and line pairs on the z -axis, respectively. (c). The left photograph shows the line pairs for the xy -plane (the left side of the photo) and z -axis (the right side of the photo). The right radiological image is a projection image of the line pair module on the xy -plane. SEDENTEXCT, safety and efficacy of a new emerging dental X-ray modality.

characteristics⁴ in scientific studies and contains the various insert modules for analysing spatial resolution, contrast resolution, pixel intensity and beam hardening artefacts (Figure 1). However, to the best of our knowledge, there has been no study on the use of the Radia diagnostic software. The aims of this study are to employ the Radia diagnostic software in combination with the SEDENTEXCT IQ phantom in CT and to evaluate its validity.

Methods and materials

The phantoms

In this study, the SEDENTEXCT IQ phantom (serial no. 016) (Figure 1a) and the Radia diagnostic software, v. 1.8 were employed. The phantom has a diameter of 160 mm, with 7 holes on the top, which are filled with the various insert modules to test spatial resolution, contrast resolution, pixel intensity and beam-

hardening artefact. And the software recognizes the required inserts on the phantom images scanned by a specific CT, locates the region of interest, measures their pixel values and returns the statistical values. As a result, this combination enabled us to analyse five tests (*i.e.* uniformity, geometric distortion, artefacts, contrast and spatial resolution semi-automatically). In the case of spatial resolution, the Radia software needs continuous slices of the phantom section 4, and recognizes five types of insert modules as an edge for a line spread function (line spread plug), a 0.25- μm wire for a point spread function (point spread plug), line pairs for the xy -plane, line pairs for the z -axis and three blanks (Figure 1b). The Radia software returned the results in table form, labelled as follows: (1) imaging information [reporting the examination settings and the digital imaging and communications in medicine (DICOM) tags information]; (2) full-width half-max point spread plug; (3) frequency and modulation transfer function (MTF) point spread plug; (4) frequency and MTF line spread plug; (5) f50 and f10 values; (6) spatial resolution xy modulation; (7) spatial resolution z modulation and (8) analysis settings. As a result, the two MTF curves on the xy -plane were obtained from the information from Radia 3 and 4, and their f50 and f10 values were obtained from Radia 5, 6 and 7. Radia 6 and 7 were expected to provide us with the results from the line pairs modules, but they often returned analysis errors. Thus, we considered that verification of the obtained results would be necessary; the details of the analysis process is protected by the manufacturer and was not made available to us.

To verify the results from the SEDENTEXCT IQ phantom and the Radia diagnostic software, we performed two additional tests. One test objectively computed the MTF based on our original wire phantom and the other test subjectively observed the line pair modules. For the MTF analysis, we employed the wire phantom with a 250 μm tungsten wire at a 2° incline against the rotating axis in the CT machine. The methodological details have been described in previous studies.^{5,6} One difference from the methodology of previous studies was the use of a 250- μm thick wire. This change in thickness corresponded to the thickness of the wire in the insert for the point spread plug of the SEDENTEXCT IQ phantom. The phantom was located in the CT in the vicinity of the rotating axis, and the continuous 100-slice images of the wire phantom were taken with the CT settings presented in Table 1. The images were analysed to compute the MTF curves using the oversampling method.⁶ This method was used to minimize the influences from the discrete data owing to pixel size and return reproducible results.⁵⁻⁷ The line pair test was performed by two observers who observed the line pair modules on the xy -plane and z -axis within the SEDENTEXCT IQ phantom (Figure 1c). The line pairs were composed of 1.0, 1.7, 2.0, 2.5, 2.8, 4.0, 5.0 line pairs per mm. The images were exported in a DICOM format, and presented using the OsiriX software (<http://www.osirix-viewer.com/index.html>). The observers evaluated

Table 1 The CT characteristics and the scanning parameters

	Sensation 64	CS9300	3D eXam
X-ray beam	Fan beam	Cone beam	Cone beam
Field of view (diameter $\times$ height in cm)	17 $\times$ 2	17 $\times$ 11	23 $\times$ 17
Tube voltage (kV)	120	85	120
Tube current (mA)	81	2	5
Acquisition time (s)	3.69	10.3	17.8
Helical pitch	0.6	–	–
Voxel size (mm)	0.33 $\times$ 0.33 $\times$ 0.6	0.25 $\times$ 0.25 $\times$ 0.25	0.3 $\times$ 0.3 $\times$ 0.3
Reconstruction kernel	H60s	Fixed bone kernel	Fixed bone kernel

the visibility of the line pairs and were allowed to change the magnification and windows freely. Any disagreements between the two observers were resolved through discussion and a consensus was reached.

CT machines

In this study, full body CT, a Somatom Sensation 64 (Siemens Healthcare, Forchheim, Germany) and two types of CBCT, a CS9300 (Carestream Health Inc., Rochester, NY) and a KaVo 3D eXam (KaVo Dental GmbH, Biberach/Riß, Germany) were used. The SEDENTEXCT IQ phantom was scanned using the settings in Table 1. The Radia software requires the whole image of the phantom to recognize the inserts automatically. Therefore, the field of view (FoV) selections were limited to the largest ones. Since the diameter of the phantom is 160 mm, we had to use CBCT machines with a FoV of at least 170 mm diameter. The obtained image data were exported in DICOM format, and analysed in the Radia. Similarly, the wire phantom was taken by these same CT machines and analysed using our original software. All the examinations were repeated three times and the data were averaged.

Statistical analysis

The values of f50 and f10 were obtained from the MTF curves, at which the MTF had dropped to 50 and 10%, respectively. The Radia software actually reported two types of f50 and f10 values (Radia 5), which were from two different calculation methods from Radia 3 (point spread plug) and Radia 4 (line spread plug). Additionally, other f50 and f10 values were obtained from the MTF curves using the oversampling method. Ideally, the three MTF curves would agree with each other. Hence, the null hypothesis of this study is that the values of f50 and f10 are not significantly different among the three MTF curves. Therefore, a one-way analysis of variance was applied against each of the f50 and f10 values. A p -value of less than 0.05 was considered to indicate a significant difference.

Sensation 64

Figure 2 The MTF curves, and the line pair images in multislice CT, Sensation 64. MTF on the *xy*-plane (a) and *z*-axis (b). The curves are representative of the three repeated measurements (c). The images show the line pairs modules, which were reconstructed with H60s kernel, with a slice thickness of 0.6 mm. MTF, modulation transfer function.

Results

The results concerning Sensation 64 are shown in Figure 2. In Figure 2a, the MTF curves on the *xy*-plane are indicated. The highest curve was from a point spread plug, followed by the curve from a line spread plug and the curve from the wire phantom. The f50 and f10 values are summarized in Table 2. In the Sensation 64, both f50 and f10 values were significantly different between the measurement methods ($p < 0.0001$). The f10 value was said to be concurrent to a resolving limitation, but a line pair was visible for 1.0 lp mm^{-1} , and not visible for 1.7 lp mm^{-1} (Figure 2c). Therefore, the resolving power would be close to 1.0 lp mm^{-1} , which approximately corresponds to the f10 value from the wire phantom. Figure 2b illustrates the MTF curves in the *z*-axis, demonstrating that both the curves from the *z* modulation and the wire phantom resemble each other. The f50 and f10 values from the wire phantom were found to be 0.93 ± 0.01 and 1.50 ± 0.01 , respectively, although the Radia did not provide the corresponding f50 and f10 values. The line pairs in the *z*-axis are shown in Figure 2c; only 1.0 lp mm^{-1} was visible, and more than 1.7 lp mm^{-1} was not visible.

The results of the two CBCT machines are shown in Figure 3. In CS9300, the MTF curves on the *xy*-plane from a point spread plug was the highest, although the curve from the wire phantom did cross the curve from the line spread plug at a frequency of $1.5 \text{ (mm}^{-1})$ (Figure 3a). This finding is also reflected in the f10 values; the f50 values were significantly different ($p < 0.0001$), but the f10 values were not significantly different ($p = 0.1941$, Table 2). In the 3D eXam, while the MTF curve from a point spread plug crossed the curve from a line spread plug, the curve from the wire phantom was lower than that of the others (Figure 3d). Both the f50 and f10 were significantly different ($p < 0.0001$, Table 2). Although the MTF curves in the *z*-axis could be drawn from the wire phantom (Figure 3b,e), the curves from the other methods could not be obtained because errors of “unable to calculate spatial resolution *z* modulation” occurred in both CBCT scans evenly. The line pairs on the *xy*-plane were visible up to 1.0 lp mm^{-1} in both the

Table 2 Spatial frequencies of *xy*-plane MTFs. The values of f50 and f10 are those spatial frequencies at which the MTF dropped to 50 and 10% of its value

	Sensation 64		CS9300		3D eXam	
	f50 ^a	f10 ^a	f50 ^a	f10	f50 ^a	f10 ^a
SEDENTEXCT IQ phantom + Radia software						
Point spread plug	1.42 ± 0.15	2.49 ± 0.29	1.11 ± 0.02	2.07 ± 0.03	0.98 ± 0.02	1.63 ± 0.02
Line spread plug	0.91 ± 0.01	1.63 ± 0.02	0.72 ± 0.01	2.12 ± 0.74	0.71 ± 0.05	2.82 ± 0.23
Wire phantom	0.61 ± 0.02	0.97 ± 0.01	0.81 ± 0.06	1.46 ± 0.09	0.56 ± 0.01	0.92 ± 0.01

MTF, modulation transfer function; SEDENTEXCT, safety and efficacy of a new emerging dental X-ray modality.

Unit: lp mm^{-1}

^aA significant difference within the row by one-way ANOVA at $p < 0.05$ level.

Figure 3 The modulation transfer function (MTF) curves, and the line pair images in the two types of cone beam CT, CS9300 (a–c) and 3D eXam (d–f). MTF on the *xy*-plane (a and d) and *z*-axis (b and e). These curves are representative of the three repeated measurements. The Radia software returned errors against the MTF in the *z*-axis and failed to demonstrate the data (c). The images show the line pairs on the *xy*-plane and *z*-axis, the slice thicknesses are the same as the voxel sizes, (i.e. 0.25 mm in CS9300 and 0.3 mm in 3D eXam).

CS9300 and 3D eXam, but those in the *z*-axis direction were not visible.

Discussion

The SEDENTEXCT IQ phantom is very frequently used⁴ and many researchers have revealed various characteristics of CBCT. Specifically, the phantom has line pair modules for the *xy*-plane and *z*-axis up to 5.0 lp mm⁻¹, which is a unique and particularly useful feature. Although the Radia diagnostic software has been developed to analyse the phantom images, there have been no studies on its use and validity. This present study might be the first report on the Radia diagnostic software. The strength of the Radia is that it can analyse images semi-automatically, and users can easily evaluate CBCT in points of uniformity, geometric distortion, artefacts, contrast and spatial resolution. However, the semi-automatic analysis requires the entire phantom images, which limits the CBCT machines, and the FoV sizes. A targeted CBCT must have a large FoV size of more than 160 mm. Kiljunen *et al*¹ listed up 45 CBCT machines in a review article, but only 11 machines could be analysed by the Radia, and in those, only the

largest FoV could be performed. In our institution, there is no CBCT with such a large size for the FoV; hence we first applied the Radia to a medical CT. After investigating the data, we hypothesized that the Radia might be optimized to CBCT, after which we decided to borrow two CBCT machines to apply the Radia. In the future, we hope the software can meet the demand for analysing images of smaller FoVs, although this might imply that the semi-automated analysis would no longer be possible. In addition, there is another problem regarding the location dependency of the MTF curves within the FoV. We previously revealed that the MTF was the highest in the centre position of the FoV, and gradually decreased as the location moved away from the centre.⁵ The Radia software could not specify the MTF measurement positions, and did not indicate its location dependency.

When the results from the wire phantom were used as a reference, the data, unfortunately, revealed many different points as shown in Figures 2 and 3. The MTF curves of the *z*-axis in Sensation 64 (Figure 2b) and the *xy*-plane from a line spread plug in CS9300 (Figure 3a) did match those from the wire phantom, but the other curves were quite different. For the resolutions of the

two CBCT scans on the z -axis, the Radia software presented an analysis error, and could not return any results. However, this error could have occurred because the line pairs on the z -axis could not be dissociated, as shown in Figure 3c,f.

In this study, we employed a wire phantom as a reference. We selected a 250- μ m diameter wire, because we wanted it to correspond to the wire thickness of a point spread plug in the SEDENTEXCT IQ phantom. Further, it was more suitable to obtain a point spread function against large pixel sizes, such as 0.25–0.30, which needed to be used because of the selection of a large FoV size. These choices might have potentially caused a metallic artefact around the wire, which could have led to a measurement error. However, the f10 values from the wire phantom were almost consistent with the visibilities of the line pairs, and the MTF curves in Sensation 64 were compatible with the results of a previous study.⁸ Alternatively, we could have tried to employ various wire thicknesses, but we had limited machine time because both CBCT machines were temporarily lent to us by the manufacturers. Instead, we did try to analyse the images from the wire insert modules and the edge insert module in the SEDENTEXCT IQ phantom, but it failed. We considered the oversampled line or point spread function to be necessary to obtain reproducible results, but the wire in the module was too short (approximately 16 mm in length) to obtain an oversampled line spread function. The short wire length limited the slice numbers to only 50 images, and the edge was too distorted to obtain an oversampled edge profile. The Radia software seemed to function on the assumption that only one slice of a point spread function or one slice of an edge profile needed to be obtained. We speculate that the Radia software might compute spatial resolutions from one slice of data image without using an oversampling method, which has probably led to the unreliable results that we obtained in this study.⁹

References

1. Kiljunen T, Kaasalainen T, Suomalainen A, Kortensniemi M. Dental cone beam CT: a review. *Phys Med* 2015; **31**: 844–60. doi: <https://doi.org/10.1016/j.ejomp.2015.09.004>
2. Project S. *Radiation protection n°172: cone beam CT for dental and maxillofacial radiology*. Luxembourg: European Commission; 2012.
3. Pauwels R, Stamatakis H, Manousaridis G, Walker A, Michielsen K, Bosmans H, et al. Development and applicability of a quality control phantom for dental cone-beam CT. *J Appl Clin Med Phys* 2011; **15**: 3478–. doi: <https://doi.org/10.1120/jacmp.v12i4.3478>
4. de Oliveira MV, Wenzel A, Campos PS, Spin-Neto R. Quality assurance phantoms for cone beam computed tomography: a systematic literature review. *Dentomaxillofac Radiol* 2017; **46**: 20160329. doi: <https://doi.org/10.1259/dmfr.20160329>
5. Ozaki Y, Watanabe H, Nomura Y, Honda E, Sumi Y, Kurabayashi T. Location dependency of the spatial resolution of cone beam computed tomography for dental use. *Oral Surg Oral Med Oral Pathol Oral Radiol* 2013; **116**: 648–55. doi: <https://doi.org/10.1016/j.ooolo.2013.07.009>
6. Watanabe H, Honda E, Kurabayashi T. Modulation transfer function evaluation of cone beam computed tomography for dental use with the oversampling method. *Dentomaxillofac Radiol* 2010; **39**: 28–32. doi: <https://doi.org/10.1259/dmfr/27069629>
7. Kwan AL, Boone JM, Yang K, Huang SY. Evaluation of the spatial resolution characteristics of a cone-beam breast CT scanner. *Med Phys* 2007; **34**: 275–81. doi: <https://doi.org/10.1118/1.2400830>
8. Watanabe H, Honda E, Tetsumura A, Kurabayashi T. A comparative study for spatial resolution and subjective image characteristics of a multi-slice CT and a cone-beam CT for dental use. *Eur J Radiol* 2011; **77**: 397–402. doi: <https://doi.org/10.1016/j.ejrad.2009.09.023>
9. Brüllmann D, Schulze RK. Spatial resolution in CBCT machines for dental/maxillofacial applications-what do we know today? *Dentomaxillofac Radiol* 2015; **44**: 20140204. doi: <https://doi.org/10.1259/dmfr.20140204>

Conclusion

In this study, we employed the Radia software combined with the SEDENTEXCT IQ phantom and evaluated its validity. The software could provide us data semi-automatically, although it could not provide data concerning the z -axis in CBCT. Further, it returned results that were statistically different from our reference data. We hope the manufacturer of the Radia software will improve on these shortcomings in the near future.

Acknowledgments

The authors would like to thank Mr Takeshi Tomoe, General Manager, from Diagnostic Imaging Division, Yoshida Dental MFG. Co., Ltd., for kindly lending a CS9300 machine and supplying the holding apparatus for the phantoms. We would also like to thank KaVo Dental Systems Japan Co., Ltd., for kindly providing us the opportunity to take the image of the phantoms using the KaVo 3D eXam machine. We would like to thank Editage (www.editage.jp) for English-language editing.

Conflicts of interest

The cone beam CT machines were lent to the authors from Yoshida Dental MFG, Co., Ltd. and KaVo Dental Systems and the holding apparatus for the phantom was made and supplied without payment by Yoshida Dental MFG, Co., Ltd.

Funding

This work was supported by the Japan Society for the Promotion of Science KAKENHI Grant Number 16K11498.