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A phantom for simplified image quality control of dental cone beam computed tomography units

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Objective. The purpose of this work was to develop an inexpensive phantom for simplified image quality assurance (IQA) together with algorithms for objective evaluation of image quality parameters and to integrate these components into an easy-to-use software package. This should help make quality control of dental cone beam computed tomography (CBCT) units accessible, easy, and affordable for any specialist or general practitioner.
Study Design. Our study developed an inexpensive polymethyl methacrylate (Plexiglas) phantom containing objects and structures for objective quantification of the most important image-quality parameters in CBCT imaging. It also paired the phantom with a software package, based on open-source software, for automatic processing and analysis.
Results. The software produces objectively measured IQA data for low- and high-contrast resolution, uniformity, noise characteristics, and geometric linearity.
Conclusions. The authors consider the phantom and methods presented in this article to be a step toward helping clinical dental personnel perform regular quality assurance on CBCT units. (Oral Surg Oral Med Oral Pathol Oral Radiol 2014;118: 603-611)

Dental cone beam computed tomography (CBCT) has been used in dental radiography for more than 10 years and has been widely available for both specialists and general dental practitioners in most developed countries. In recent years, the use of CBCT has grown rapidly, especially in the fields of implant dentistry, orthodontic treatment, and endodontic treatment. Major concerns have been raised regarding the indications for use of CBCT because of the radiation doses that patients receive. A multinational task group ("Sedentexct") was set up within the Seventh Framework Programme of the European Atomic Energy Community (Euratom) to systematically analyze the evidence regarding the application of CBCT in clinical situations and to publish guidelines for its proper use.[1] Quality assurance (QA) of CBCT units is a particularly important issue addressed in the guidelines.

QA procedures can be divided into 2 groups: Dosimetric QA and image QA (IQA). Dosimetric QA should be carried out by a medical physics expert or clinical engineer using properly calibrated equipment, whereas IQA should preferably be done by clinical workers: Dentists, dental nurses, or hygienists. IQA should also be carried out more frequently than dosimetric QA; monthly IQA should be considered good practice. In addition, software upgrades demand additional IQA.

QA methods in radiology, especially medical radiology, have traditionally been developed by physicists and engineers. To carry out QA, medical radiology departments have engaged physicists and engineers, some as department employees, others as consultants from dedicated service companies, or service personnel from the manufacturers or vendors. In dental radiology, however, this has not been the case. QA procedures have generally been performed by service engineers from the vendors and, up to now, have focused on intraoral and, to some extent, panoramic equipment. The service organizations of the vendors are not suited to the task of doing QA, especially IQA, at the level and frequency that high-quality CBCT requires.[1,2]

Furthermore, evaluation of image quality using commercially available phantoms (e.g., those from QRM

Statement of Clinical Relevance

Image quality assurance for cone beam computed tomography procedures is essential for maintaining good diagnostic accuracy. It is important that the clinical personnel are engaged in performing tests on a regular basis, using easy and understandable procedures.

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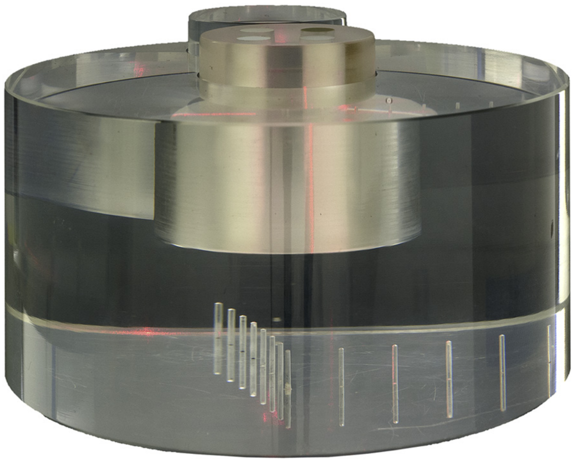

Fig. 1. Photograph of the phantom.

GmbH or Leeds Test Objects Ltd) depends, to a great extent, on methods requiring subjective evaluations. In our opinion, we need objective evaluation methods for IQA. These methods, which must be used frequently by clinical personnel, should be very easy to perform and must not be time-consuming. Ideally, they should be operated without user input and produce results that are easily understandable, such as "passed" or "failed." To set action levels for production of such binary results requires a vast amount of measured data as input and a thorough analysis of diagnostic outcome when data for the measured parameters are impaired. Therefore, time and experience are needed to propose action levels for the parameters studied in the IQA. Additionally, to be accepted by general practitioners, equipment that the clinic must purchase for IQA must not be too expensive. In a recent publication,[3] a phantom and dedicated software for IQA were presented. That publication also promoted measurement of the same IQA parameters as used in this article, with the difference that measurement of spatial resolution is made also in the Z direction using an edge spread function and that a hole pattern for subjective evaluation of the spatial resolution limit also is used. At this stage, the simplified method described in this article does not quantify the spatial resolution in the Z direction. However, their phantom, also constructed for objective measurements, is highly sophisticated and is intended for use by physicists and engineers. Furthermore, the minimum field size for IQA with their proposed procedures is 10 × 10 cm. We believe that simple IQA using smaller field sizes is even more important. Ideally, it should be possible to acquire in 1 scan all of the IQA parameters needed to describe the status of the unit, even for the smallest field of view used.

In the era of analog imaging, IQA methods relied on imaging of phantoms followed by subjective evaluation of the quality parameters using the x-ray film and a light box. Even for the intrinsic digital modalities, such as CT, hardcopies from a laser printer were viewed on a light box for QA purposes. Subjective evaluation, however, has major drawbacks and many confounding factors that inevitably will affect the results obtained. Surprisingly, the use of images of QA phantoms that require subjective evaluation has persisted for many years in the field of digital imaging. An important step toward improved IQA methods is therefore to replace subjective evaluation with objective measurements that directly make use of the digital image data.

Thus, the aim of this work was to develop an inexpensive phantom for IQA together with algorithms for consistent, objective evaluation of image quality parameters and to integrate these components into an easy-to-use software package. This equipment will help make quality control of dental CBCT units easy and affordable.

MATERIAL AND METHODS

QA phantom

The phantom was constructed for the purpose of measuring a subset of the IQA parameters that are normally measured by medical physics experts or clinical engineers when doing IQA for medical computed tomography (CT) units or for CBCT units for angiography, radiotherapy, or odontology. From long experience of medical CT QA, the parameters chosen are those that are most important to measure, and the combined result will certainly reflect the condition of the CBCT unit. The IQA procedures chosen are uniformity, noise, contrast linearity, geometric accuracy, low-contrast resolution, and spatial resolution. As suggested by Baek and Pelc,[4] the noise power spectrum is also produced.

The main body of the phantom consists of a polymethyl methacrylate (Plexiglas) cylinder with a diameter of 160 mm (to mimic the x-ray attenuation of a human head) and a height of 70 mm. Two cylindrical cavities, each with a diameter of 50 mm and a depth 40 mm, are drilled into the top of the cylinder. One cavity is placed in the middle of the phantom and the other is centered between the first cavity and the edge of the phantom. Measurements can therefore be made in the center or the periphery of the phantom. Peripheral measurements are important because radiologic CBCT examinations target structures located peripherally on the human head. The bottom of the phantom receives 15 holes, each 1 mm in diameter and 5 mm deep, with a distance of exactly 10 mm between the holes, and with the holes drilled in 2 perpendicular lines. Figure 1 shows a photograph of the phantom, and Figure 2 presents drawings of the main body of the phantom.

Two cylindrical inserts 50 mm in diameter and 50 mm tall were manufactured to fit the phantom; one of solid Plexiglas and the other with four 10-mm-diameter