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A new image quality measure in CT: Feasibility of a contrast-detail measurement method

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ABSTRACT

Purpose: To develop a new method of evaluating image quality in computed tomography (CT) using an objective measure of low contrast-detail (LCD).
Method: To achieve this aim a new LCD-CT (CDCT) phantom needed to be designed and developed. A CT inverse image quality figure (CT-IQFinv) value, based on the planar radiography LCD method, was also devised. Validation of the CDCT phantom design and CT-IQFinv calculations were undertaken using 67 observers and software methods. The CDCT phantom was scanned on three multi-detector CT systems using variable factors of kVp, mAs and slice thickness.
Results: The results were compared to an *a priori* knowledge that image quality improves with increased photons reaching the detectors. Observer CT-IQFinv scores for the phantom's peripheral region were consistent with the *a priori* knowledge and generally consistent in the inner region, with one exception. The software CT-IQFinv scores for the phantom's peripheral region were also consistent with the *a priori* knowledge, however there were some inconsistencies. Software and observer CT-IQFinv score differed significantly ($p < 0.05$) however both were consistent with the *a priori* knowledge.
Conclusions: The work reported is designed as proof of concept of development of LCD measure in CT. CT-IQFinv can be used as a measure of LCD image quality in CT when evaluating CT parameter of mAs, kVp and slice thickness. The results demonstrate potential for use of CT IQFinv, however at present further work is needed to overcome design and technical issue encountered in this project.

Introduction

Computed tomography (CT) scanning is used extensively in diagnostic imaging. The main advantage of CT scanning compared to planar X-ray imaging is its capability to provide low contrast resolution which allows the visualisation of low contrast lesions.[1,2] In CT, low contrast detail and lesion detection are primarily limited by noise which can be reduced by increasing radiation dose. Higher radiation doses results in lower image noise and hence there is improved visualisation of low contrast objects.[1–4] CT technology is advancing rapidly however these advances have improved temporal resolution; contrast and spatial resolution have not significantly improved.[5,6] Image quality and radiation dose optimisation still remain a central goal in CT examinations.[7–10]

Planar digital radiographic image quality in computed radiography (CR) and digital radiography (DR) also improves with increasing radiation dose.[11] In CR and DR alternative approaches of image evaluation incorporate methods that evaluate both image spatial detail and image contrast have been used. The evaluation method of low contrast-detail (LCD) detectability is commonly used in digital planar radiography and is claimed to be an appropriate method for image quality optimisation.[12–17] The software method of LCD detectability evaluation showed high reliability and validity in evaluating and optimising the images of digital radiography.[14,18–20] LCD detectability performance is an effective tool to understand the influences of image quality factors and radiation dose reduction parameters in clinical digital radiography.[14,21] The use of contrast-detail measurements through the calculation of the inverse image quality figure (IQFinv) as a measure of LCD in digital planar radiography has been shown to be a valid method.[11,22–24]

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In CT the detectability of LCD objects is affected by object size/diameters, subject contrast and noises in its various forms. The factors that affect these include the radiation dose associated with protocol parameters, the type of reconstruction method and the objects locations in the scan field. The peripherally located objects in the radiation field received more dose than the centre ones.[25] As such there is a difference in image quality between the centre of the image and the peripheral regions.[1,2,26,27]

CT LCD detectability evaluation methods, with higher validity and reliability, have not been yet achieved despite the efforts that are being conducted by several institutions and expert researchers.[1] Some low contrast CT phantoms are available.[1,2] The current quality assurance phantoms are not used to measure LCD and they need to simulate clinical condition more before they can be used to fully assess image quality.[28–30]

The ability to measure LCD detectability performance in CT has not previously been applied at the same level as in planar X-ray. Given the limitations of current phantoms in LCD measurement, a new phantom and approach was developed to measure the LCD detectability of CT. Effects in the image from changes to scan parameter or protocols may not be evident to an observer but may affect the LCD in the image. To ensure that a new contrast-detail CT (CDCT) phantom is able to evaluate the full range of LCD, objects of size below CT detection threshold need to be incorporated into the design. The design of a new LCD CT phantom should also incorporate methods to evaluate the LCD in both of the central and peripheral regions of the phantom.

This study also aimed to establish the proof of concept of LCD measurement in CT and validate the new methodology of LCD detectability. As such the new CDCT phantom and LCD measurement method could be used by CT radiographers to evaluate image quality.

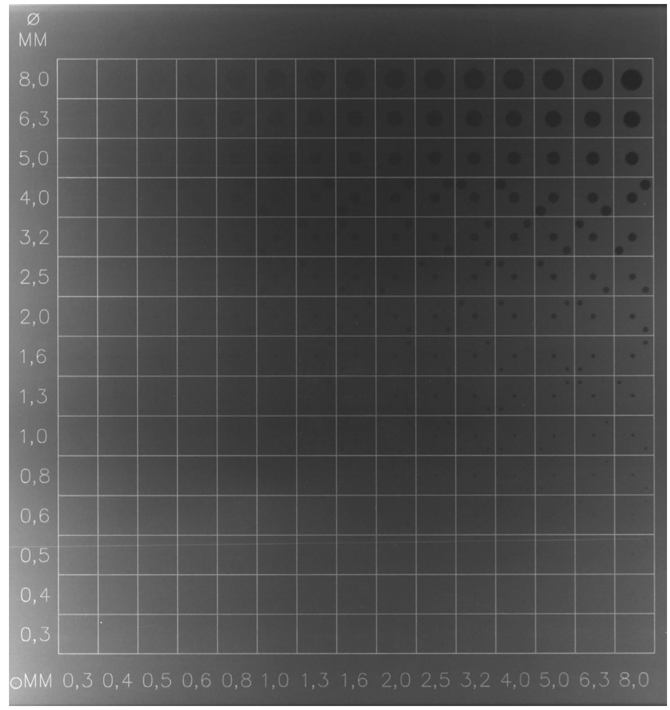

Figure 1. Planar X-ray image of the CDRAD phantom.

Method

Phantom design and image quality figure

In planar digital radiography, CDRAD phantom (Artinis Medical Systems, Elst, Netherlands) images are used as a measure of image quality. Fig. 1 shows an example image. For the use in planar radiography the IQFinv is expressed mathematically[14,22,23] as:

$$IQFinv = \frac{100}{\sum_{i=1}^{15} C_i \cdot D_{i,th}} \tag{1}$$

where: C_i is the depth of the hole in the contrast column *i*, *and*

$D_{i,th}$ is the smallest visible diameter or the threshold diameter in contrast column.

For this work a prototype CDCT phantom was designed and developed in cooperation with Artinis Medical Systems (Elst, Netherlands). The objective in designing the new phantom was to include objects, in both size and contrast levels, that are below the detectability of either the observer or the software being used to determine the LCD. The CDCT phantom is 32 cm diameter in size and 12 mm in thickness. It was manufactured with the phantom body being plastic water and includes 192 cylinder objects of 10 mm length. The objects are of eight different sizes and eight different CT attenuations sited in two different regions within the phantom. The CDCT phantom's specifications of each object are listed in Tables 1a and 1b and it layout is shown in Fig. 2.

To determine the HU values of the objects the CDCT phantom was scanned using three multi detector CT (MDCT) scanners, a 16-MDCT system (LightSpeed, GE Healthcare), a 64-MDCT system (LightSpeed VCT, GE Healthcare) and an 80-MDCT system (Aquilion Prime 80, Toshiba). Scan parameters used were 120 or 140 kVp and 200 mA s and 5 mm slice thickness at each kVp setting. The CDCT phantom was centred in the CT gantry and supported in vertical position. The resultant images were captured and stored as DICOM images. Fig. 2 shows a typical CT image of the CDCT phantom.

Measurements of attenuation characteristics of each object in the CDCT phantom and the phantom's background material were made. The phantom was scanned three times at each exposure factor. Regions of interest (ROI) were placed in each of the three largest sized objects and the phantom's background to measure the HU of the objects. The average HU and standard deviation at each kVp were recorded.

The method of calculation of the LCD measurement in CT was based on the methods used to calculate the planar radiographic IQFinv (Eq. (1)). Contrast of the object in CT can be determined by the attenuation differences, measured in HU, of the object from the surrounding background divided by the background value. As some objects in CT have negative HU values, the absolute value of the relative contrast (CVabs) of each object was needed to be determined due to positive and negative, compared to the background, HU value objects. The CVabs is mathematically expressed as:

$$CVabs = \left| \frac{HU_{obj} - HU_{bkg}}{HU_{bkg}} \right| \tag{2}$$

where: HU_{obj} is averaged HU of the object from the scanners, *and*

HU_{bkg} is averaged HU of the phantom background from the 3 scanners and 2 kVp setting used on each scanner.