Parameter-based estimation of CT dose index and image quality using an in-house android™-based software

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Abstract. Compromise between radiation dose and image quality is essential in the use of CT imaging. CT dose index (CTDI) is currently the primary dosimetric formalisms in CT scan, while the low and high contrast resolutions are aspects indicating the image quality. This study was aimed to estimate CTDIvol and image quality measures through a range of exposure parameters variation. CTDI measurements were performed using PMMA (polymethyl methacrylate) phantom of 16 cm diameter, while the image quality test was conducted by using catphan® 600. CTDI measurements were carried out according to IAEA TRS 457 protocol using axial scan mode, under varied parameters of tube voltage, collimation or slice thickness, and tube current. Image quality test was conducted accordingly under the same exposure parameters with CTDI measurements. An Android™ based software was also result of this study. The software was designed to estimate the value of CTDIvol with maximum difference compared to actual CTDIvol measurement of 8.97%. Image quality can also be estimated through CNR parameter with maximum difference to actual CNR measurement of 21.65%.

1. Introduction

Tomographic imaging is commonly used to get 3D image for diagnostic purposes. CT-scan contributes on 10-50 times, even 500 times greater radiation dose than conventional X-ray [1]. Until recently, CT-dose index (CTDI) is a dosimetry parameter used in CT imaging. CTDI is measured by using homogeneous cylindrical Polymethyl Methacrylate (PMMA) phantom [2–4]. There were two diameter sizes of standard PMMA phantom; 16 cm to represent adult heads and paediatric bodies, and 32 cm to represent adult bodies.

Beside the dosimetry, image quality, being directly afflicted by exposure parameters (kV/HVL, mAs, and slice thickness), is also essential in determining the performance of a CT-scanner. As a matter of principle, clinically acceptable image and patient dose being as low as reasonably achievable (ALARA) should be achieved for optimization purposes. This work was aimed to estimate CTDIvol and image quality measures through a range of exposure parameters variation (kV, mAs and axial thickness). In addition, Android™ based software was developed to provide relatively quick assessment to perform preliminary optimization.
2. Materials and methods
The CT-scanner used in this work was GE Brightspeed Series 317010HM7 in Cipto Mangunkusumo National Central Hospital, Jakarta. The maximum tube rate of this CT was 140 kV and 345 mA. Image quality was evaluated using Catphan® 600 as an object scan.

2.1. Dose measurement
Dose was assessed by measuring CTDIvol on 16 cm PMMA phantom using Unfors Xi-CT. The exposures were done using 2 second rotation time and axial scan mode. The parameter variation used can be observed on table 1.

CT dose index (CTDI) or CT air kerma index was calculated through equations (1), (2), and (3)

\[
C_a,_{100} = \frac{1}{nT} \int_{50}^{+50} K(z) dz
\]

\[
C_W = \frac{1}{3} \left( C_{PMMA,100,c} + 2C_{PMMA,100,p} \right)
\]

\[
C_{VOL} = C_W \frac{nT}{\text{pitch}}
\]

with \( C_{a,100} \) refers to CT air kerma in free air; \( C_{PMMA,100,c} \) refers to CT air kerma in centerof PMMA phantom meanwhile \( C_{PMMA,100,p} \) refers to CT air kerma in periphery; \( C_w \) refers to weight CT air kerma; \( C_{vol} \) refers to volume CT air kerma that includes helical pitch or axial scan spacing in calculation; \( nT \) is nominal beam width; \( K(z) \) is air kerma value along z-axis; and \( l \) being the distance for a single rotation gantry [5].

2.2. Image quality measure
The analysed image quality aspects were low contrast resolution and spatial resolution. Low contrast resolution was evaluated using Catphan® 600 single scans on CTP 515 marked position. CNR (Contrast to Noise Ratio) was chosen as the quantity to represent low contrast resolution. The CNR was evaluated using Region of Interest (ROI) analysis on supra-slice section with 15 mm in diameter on 1% contrast level (Figure 1a) and was subsequently calculated using equation (4)

\[
\text{CNR} = \frac{\bar{x}_s - \bar{x}_{bg}}{\sigma_{bg}}
\]

with \( \bar{x}_s \) being mean of ROI gray-scale value on each image sample (supra-slice 15 mm in diameter), \( \bar{x}_{bg} \) being mean value of ROI gray scale value on background and \( \sigma_{bg} \) being the background noise [3].

On the other hand, high spatial resolution was evaluated using Catphan® 600 scans on point CTP 528 and was evaluated using Modulation Transfer Function (MTF) curve. The MTF curves were evaluated by using ROI on test pattern beginning with 1.0 linepair/cm frequency to the last visually-separable objects (as seen on figure 1b).

| Table 1. Exposure parameter variations. |
|-----------------|-----------------|-----------------|-----------------|-----------------|
| kV  | mAs | Slice thickness, no. of image/acquisition |
| 120 | 400 | 10 mm, 1 image |
| 100 | 300 | 5 mm, 1 image |
| 80  | 200 | 0.625 mm, 2 images |
From each ROI, Graph of optical density (gray value) was observed. Square Wave Response Function (SWRF) would be observed in accordance with the graph. SWRF \( r(u) \) (\( u \) was test pattern frequency) was evaluated using equation 5. Figure 2 was given to explaining this paragraph.

\[
    r(u) = \frac{\Delta B_2/\Delta B_1}{B_2/B_1} = \frac{(\text{max} - \text{min})}{(\text{max} + \text{min})} \frac{2}{1}
\]

Each SWRF values were normalized on values of smallest test pattern frequency (1.0 linepair/cm). Afterwards, curves would be made of frequency (linepair/cm) versus normalized SWRF using MATLAB curve fitting through equation 6.

\[
    f(u) = \frac{c \exp\left(-\frac{\pi^2 u^2}{d}\right) + a (1 + 4\pi^2 u^2/b^2)^{-1}}{c + a}
\]

\( a, b \) and \( c \) were the values to be solved for [7]. By performing Fourier Transform on the curve fitting \( f(u) \), MTF curve was estimated. Term-12 Fourier Transform was applied in the calculation (equation 7).

\[
    R(u) = \frac{\pi}{4} \left[ r(u) + \frac{r(3u)}{5} + \frac{r(5u)}{7} + \frac{r(7u)}{11} - \frac{r(11u)}{13} - \frac{r(13u)}{15} - \frac{r(15u)}{17} + \frac{r(17u)}{19} + \frac{r(19u)}{21} + \frac{r(21u)}{23} - \frac{r(23u)}{29} \right]
\]

3. Results and discussion

3.1. Parameter-based CTDI estimation

Correlation between each exposure parameters (kV, mAs, and beam collimation) to CTDI\(_{vol}\) or nCTDI (CTDI\(_{col}/mAs\)) was first investigated, particularly the correlation between mAs and CTDI\(_{vol}\), kV and nCTDI, as well as collimation with nCTDI. Each parameter correlations is given on figure 3, allowing
interpretation of linear correlation between mAs and CTDI\textsubscript{vol} as well as kV\textsuperscript{2.5} and nCTDI with R\textsuperscript{2} exceeding 0.9 (figure 3). An equations relating between collimation and nCTDI was also formulated. The linearity between kV and nCTDI as well as collimation and nCTDI allowed equation 8 to be applied to estimate nCTDI \((n\text{CTDI\textsubscript{estimation}})\) or CTDI\textsubscript{estimation}.

\[ n\text{CTDI\textsubscript{estimation}} = \frac{f_{kV}(k')}{f_{kV}(k)} \times \frac{kV^{2.5}}{kV^{2.5}} \times n\text{CTDI}_{kV,k} \]  

(8)

The deviation between CTDI\textsubscript{estimation} and actual CTDI measurement was found to be below 5%. However, two data points have demonstrated deviations of above 5%. The deviation ranges between CTDI\textsubscript{estimation} and actual CTDI measurement were in the range of 0.36% to 8.97%.

![Figure 3](image.png)

**Figure 3.** Correlations between (a) mAs and CTDI and (b) kV\textsuperscript{2.5} and nCTDI

3.2. Predicting image quality from exposure parameter

Image quality can be represented either by SNR (signal to noise ratio) or CNR (Contrast to Noise Ratio). As discussed by (Bushberg, et al., 2012), dose is proportional with squared SNR divided by slice thickness [3]. In this work, correlation between CTDI\textsubscript{estimation} and CNR squares divided by slice thickness was chosen to predict image quality. Linear curve fitting between CTDI\textsubscript{est} and \(\frac{\text{CNR}^2}{T}\) demonstrated the regression coefficient value of exceeding 0.9. Therefore, the equation was chosen to be applied in estimating CNR with the formula being given on equation 9.

\[ \text{CNR}_{\text{est}} = \sqrt{(0.01966 \times \text{CTDI}_{\text{calc}} + 0.11167) \times \text{slice thickness}} \]  

(9)

The deviation between CNR\textsubscript{estimation} and actual CNR measurement was found to be below 5.0% in thirteen data points, while other data points have deviations of above 5.0%. The deviation ranges between CNR\textsubscript{estimation} and actual CNR measurement were in the range of 0.04% to 21.65%. In this work, correlation between exposure parameters and high contrast resolution was not identified using MTF curve due to the inability of the varied exposure parameters to provide a variation of image quality, therefore requiring further study. However, the idea of Goldman (2007) that the primary factors affecting spatial resolution are focal spot size, patient motion, matrix size and reconstruction filter [8] supports our result.

3.3. Android\textsuperscript{TM} based software to estimate CTDI and CNR

The Android\textsuperscript{TM}-based software allowing user to estimate dose information (CTDI\textsubscript{vol} and DLP) and image quality (CNR) through parameter exposure input (kV, mAs, collimation or slice thickness) was developed using MIT app Inventor. Whenever selected parameter combination yields on dose
index exceeding European Commission EUR 1626 (2000) a certain warning message will appear. Image quality in terms of CNR was grouped (labelled) into categories A, B, and C, each for images yielding $\text{CNR} \geq 2.7$, $1.67 < \text{CNR} < 2.7$, and $\text{CNR} \leq 1.67$, respectively, to provide quick decision making. The software layouts are given on figure 4.

![Software Layouts](image)

**Figure 4.** The android software layouts

4. Conclusion

In-house Android™-based software was developed and can be used to estimate CTDI$_{vol}$ or CNR through exposure parameters combination input. The software have deviation in the range of 0.36% to 8.97% and 0.04% to 21.65% to estimate CTDI$_{vol}$ and CNR on adult head examination, respectively. The algorithm was tailored to the unit used to commission the software.

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