Investigation of the characteristics of Automatic Exposure Control (AEC) of a Computed Tomography (CT) scanner by utilising cylindrical and anthropomorphic phantoms

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Abstract. One method to optimise the use of x-rays in CT and hence a reduction in patient dose is the application of automatic exposure control (AEC). This study measured the effective mAs, image noise and volume CT dose index (CTDIvol) as the result of changing the AEC index on a Siemens Somatom Definition 64 slices dual source CT scanner. The scans were performed on four phantoms of different geometries, namely the 16 and 32 cm cylindrical CTDI phantoms and two anthropomorphic phantoms, RANDO (20 cm effective diameter) and ATOM (19.8 cm effective diameter). Results showed that the effective mAs increased with increasing tube potential (kVp) and Quality Reference mAs (QRM), therefore increasing CTDIvol while reducing image noise. Meanwhile, no changes of radiation dose and image noise were observed when the pitch was increased. However, for the largest phantom (32 cm effective diameter), a constant effective mAs was found between 120 and 140 kVp. The same trend was also found with increasing QRM from 300 mAs to 400 mAs suggesting a certain limitation of the AEC has been reached. In conclusion, this study showed that AEC is affected by kVp and QRM but not by pitch selection. Further work is required to quantify the characteristics of the AEC system in relation to the mentioned parameters for better optimisation.

1. Introduction
Computed Tomography (CT) has been used over 45 years and has undergone a lot of improvements. Consequently, its development boost the number of CT examinations, which resulted in the highest collective dose among medical imaging modalities [1-2]. Previously, in order to reduce radiation dose, a fixed tube current was utilised where the user manipulates the tube current based on patient size. However, the human body is not homogenous along the direction of scan. This resulted in different dose absorption in a patient. Therefore, CT manufacturers introduced an automatic exposure control (AEC) system to reduce the radiation dose accordingly to patient sizes and variation in thickness to produce a better image quality [2-5].

The modulation of tube current can be influenced by patient positioning [6-8], size, attenuation properties in different regions of the body, and technical factors such as tube potential (kVp), Quality reference mAs (QRM) and pitch [9-11]. QRM is the technical factor used by Siemens AEC system
(CARE Dose4D) to represent the required image quality. The aim of this study was to investigate the effect of AEC system on the radiation dose delivered and image noise based on various phantom geometries. In addition, the influences of kVp, QRM, and pitch to the modulated effective mAs in AEC system were also studied.

2. Methods and materials
Four phantoms including a 32 cm and 16 cm Computed Tomography Dose Index (CTDI) phantom, adult female ATOM (CIRS, Norfolk, Virginia, USA) and RANDO (model ART-300A, Radiology Support Devices, Inc., Long Beach, CA, USA) phantom were scanned by using Siemens AEC system (CARE Dose4D) of a 64 slices dual source CT scanner (Somatom Definition AS, Siemens, Erlangen, Germany). In this study, only the abdominal region was investigated. The size of the phantoms is represented by effective diameter given by the following equation [1]:

$$\text{effective diameter} = \sqrt{\text{Lateral} \times \text{Anteriorposterior}} \quad (1)$$

in which the size of 16 cm and 32 cm CTDI, ATOM and RANDO phantom were 16 cm, 32 cm, 19.8 cm and 20 cm respectively.

The parameter used during scanning was shown in Table 1. The entire phantom had been scanned by varying the kVp (80 kVp, 100 kVp, 120 kVp, 140 kVp), Quality Reference mAs (QRM) (50 mAs, 100 mAs, 210 mAs, 300 mAs, and 400 mAs) and pitch (0.85 and 1.5). For pitch study, only the RANDO phantom was used. Three central slices were used for the measurement. Radiation dose was represented by CTDI and image quality was represented by image noise. Image noise evaluation was made by using RadiAnt DICOM viewer (Medixant, Poznan, Poland) and Syngo Fastview (Siemens AG, Berlin and Munchen). Four identical 3cm² region of interests (ROIs) were drawn on the central slice image and the average of the standard deviations (SD) of the four ROIs was considered to represent the image noise (refer to Figure 1).

Table 1. Parameters used during CT scanning.

| Parameters          | Adult Protocol |
|---------------------|----------------|
| Pitch factor        | 0.85           |
| Direction of scan   | Craniocaudal   |
| Slice thickness     | 0.75 mm        |
| Scan time           | 6.09 s         |
| Rotation time       | 0.5 s          |

| Parameters          | Adult Protocol |
|---------------------|----------------|
| Recon slice         | 0.75 mm        |
| Recon kernel        | B20f smooth    |
| Recon window        | abdomen        |
| Recon increment     | 0.7 mm         |

Figure 1. A screen-capture showing the image noise evaluation for RANDO phantom. The same technique was implemented for the other phantoms.
3. Results and Discussions
Similar trends were observed for measurements made on the 16 cm CTDI phantom, RANDO and ATOM phantom. For the simplicity of presentation, only the measurements of RANDO phantom was shown in Figure 2a, 3a and 4a. Figure 2b, 3b and 4b showed a different trend when using 32 cm CTDI phantom. In Figure 5, only 120 kVp was shown due to the similar trend observed for 80 kVp, 100 kVp and 140 kVp.

![Graph](image1.png)

(a)

![Graph](image2.png)

(b)

**Figure 2.** Modulation of effective mAs for varying QRM and kVp by using (a) RANDO and (b) 32 cm CTDI phantom.
Figure 3. Image noise for varying QRM and kVp by using (a) RANDO and (b) 32 cm CTDI phantom.

Figure 4. Radiation dose for varying QRM and kVp by using (a) RANDO and (b) 32 cm CTDI phantom.

Figure 5. Influence of pitch for (a) modulation of effective mAs (b) radiation dose for RANDO phantom with 120 kVp.
3.1. Influence of QRM on effective mAs, image noise and radiation dose

On the influence of QRM to effective mAs, when the QRM was increased the effective mAs also increased. QRM is the technical factor used by the Siemens AEC system (CARE Dose4D) to represent the required image noise. In order to achieve the prescribed image noise, the AEC system modulates the effective mAs.

In general, increased QRM represents lower image noise, which is achieved by increasing the effective mAs and subsequently increasing the radiation dose. Figure 2, 3 and 4 shows the effect of modulating the QRM on the effective mAs, image noise and radiation dose respectively.

This trend was observed for the measurement using the RANDO phantoms (shown in Figure 2a, 3a and 4a). In contrast, a slightly different trend was observed for measurements made in the 32 cm CTDI phantom (shown in Figure 2b, 3b and 4b). Using the 32 cm phantom, increasing QRM increases the effective mAs (refer to Figure 2b). This resulted in increased radiation dose (Figure 4b) and decreased image noise (refer to Figure 3b). However, when increasing QRM 300 mAs to 400 mAs, the changes in the effective mAs was different for 80 kVp, 100 kVp and 140 kVp compared to the 120 kVp (refer to Figure 2b). This variation was due to the AEC system pursuing the prescribed image noise. In addition, it was also observed that increasing from QRM 300 mAs to 400 mAs for every kVp used, the radiation dose was constant (refer to Figure 4b) as well as for the image noise (refer to Figure 3b). This result showed that the AEC system was limiting the dose delivered when QRM 400 was used for 32 cm effective diameter phantom.

3.2. Influence of kVp on effective mAs, image noise and radiation dose

On the influence of kVp to effective mAs, when the kVp was increased the effective mAs also increased. This trend was observed for the measurement using the 16 cm CTDI phantom, RANDO and ATOM phantoms (shown in Figure 2a). This resulted in an increase of radiation dose and a decreased image noise (shown in Figure 3a and 4a). In contrast, a slightly different trend was observed for measurements made in the 32 cm CTDI phantom (shown in Figure 2b, 3b and 4b). Using the 32 cm phantom, increasing kVp decreases almost constantly the effective mAs (refer to Figure 2b). This variation was due to the AEC system pursuing the prescribed image noise. However it resulted in increased radiation dose (Figure 4b) and decreased image noise (refer to Figure 3).

The previous result showed that increasing effective mAs resulted in an increase of radiation dose and a decrease in image noise. However, based on the influence of kVp to effective mAs for 32 cm diameter phantom, it showed that a decrease in effective mAs resulted in an increase of radiation dose and a decrease of image noise (refer to Figure 3b and 4b). In this case, it is due to higher kVp increasing the ability of photons to penetrate the phantom and therefore more photons were being collected. This reduced the image noise and from the exposure of high energy photons, radiation dose was increased. In addition, this result also showed that the relations of image noise as an inverse function of the square root of mAs was not obeyed for 32 cm phantom.

It was also observed that increasing from 120 kVp to 140 kVp for every QRM used, the radiation dose was constant (refer to Figure 4b). This result showed that the AEC system was limiting the dose delivered when 140 kVp was used for the 32 cm diameter phantom.

3.3. Influence of pitch on effective mAs and radiation dose

On the influence of pitch to effective mAs and radiation dose, no significant change was observed. CARE Dose4D uses effective mAs setting in which the effective mAs will be constant although there is a change in pitch, consequently the mA will be increased as the pitch increased (i.e. for a 1 s rotation time and 240 effective mAs, mA is 240 mA with pitch of 1 but uses 300 mA with pitch of 1.25) and it is governed by the following equation [8]:

\[ \text{effective mAs} = \frac{mAs}{\text{pitch}} \quad \text{(2)} \]

However, QRM 400 mAs showed that an increase in pitch resulted in a decrease in radiation dose (refer to Figure 5b). This result shows that the AEC system was limiting the dose delivered when QRM 400 mAs was used for the 32 cm diameter phantom.
4. Conclusions
This study showed that tube potential and selection of QRM affects the radiation dose and image noise for small and medium size patients (16 – 20 cm effective diameter), represented by 16 cm CTDI, RANDO and ATOM phantoms. However, for large size patients, such as represented by the 32 cm diameter CTDI phantom, a similar trend was observed for QRM settings ≤ 300 mAs. Beyond QRM 300 mAs, the modulation of the effective mAs appears to be restricted by the CT internal system, shown as a plateauing of the effective mAs and subsequently limiting the radiation dose delivered to patients. This effect is particularly prominent for higher tube potentials (≥120 kVp).

Pitch factor is often used as a scanning parameter that can reduce the radiation dose. However, our study showed that when the AEC system is switched on, changing the pitch from 0.85 to 1.5 (i.e. from overscanning to underscanning the patients), the effective mAs was kept constant. As a result, no radiation dose reduction would be expected.

Overall, this study showed the importance of understanding the characteristics of specific AEC system as it can influence the radiation dose delivered to the patient.

5. References
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