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Söderberg, Marcus

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Total number of authors:
1

LUND UNIVERSITY

PO Box 117
221 00 Lund
+46 46-222 00 00

OVERVIEW, PRACTICAL TIPS, AND POTENTIAL PITFALLS OF USING AUTOMATIC EXPOSURE CONTROL IN CT – SIEMENS CARE DOSE 4D

Author: Marcus Söderberg

Address: Medical Radiation Physics Malmö, Department of Translational Medicine, Lund University, Skåne University Hospital, SE-205 02 Malmö, Sweden

Telephone: +46 40 33 86 51

Fax: +46 40 96 31 85

E-mail: marcus.soderberg@med.lu.se

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OVERVIEW, PRACTICAL TIPS, AND POTENTIAL PITFALLS OF USING AUTOMATIC EXPOSURE CONTROL IN CT – SIEMENS CARE DOSE 4D

Marcus Söderberg

ABSTRACT

Today, computed tomography (CT) systems routinely use automatic exposure control (AEC), which modulates the tube current. However, for optimal use, there are several aspects of an AEC system that need to be considered. The purpose of this study was to provide an overview of the Siemens CARE Dose 4D AEC system, discuss practical tips, and demonstrate potential pitfalls. Two adult anthropomorphic phantoms were examined using two different Siemens CT systems. When optimizing the CT radiation dose and image quality, the projection angle of the localizer, patient centring, protocol selection, scanning direction, and the use of protective devices require special attention.

INTRODUCTION

The gradually increasing awareness of radiation exposure, mainly from computed tomography (CT) examinations, has forced manufactures to develop techniques to reduce radiation doses(1). Several methods and techniques are available, and all major CT manufacturers currently offer systems with automatic exposure control (AEC)(2). These systems modulate the tube current as a function of the projection angle and along the scanning direction according to the patient's size, shape, and the attenuation of the body parts being scanned. The aim of AEC is to optimize the dose utilization, i.e. obtain the pre-determined image quality with improved radiation efficiency. The basic principles behind the systems are similar, but they operate somewhat differently(2). All systems base the tube current modulation on attenuation data from the localization radiograph (localizer); while, some systems also use changing angular attenuation profiles.

There are several benefits of using AEC systems, including: improved radiation efficiency, improved consistency of the quality of images among different sized patients, reduction of starvation artefacts, and reduced load on the X-ray tube, which increases its lifetime. However, there are limitations and pitfalls to be aware of. The response of AEC systems to variations in the scan and reconstruction parameters differs among the manufacturers, models, and software versions(3,4). The behaviour of the tube current adaptation in regions with high-attenuated metal implants also varies(5,6). The localizer is fundamental to AEC systems because it is used to determine the adequate tube current level. Therefore, to ensure optimal image quality and the minimal radiation dose, it is important to minimize patient movements between the localizer and subsequent scans, include the entire region to be scanned on the localizer, pay careful attention to patient centring, and apply any in-plane protective device, such as bismuth shielding, after the localizer(7). For optimal use, there are several aspects of an AEC system that need to be considered and there are substantial differences between the systems.

The purpose of this study was to provide an overview of the Siemens CARE Dose 4D AEC system, discuss practical tips, and demonstrate potential pitfalls regarding the projection angle of the localizer, centring of the patient, protocol selection, scanning direction, and use of protective devices.

MATERIALS AND METHODS

CARE Dose 4D

The CARE Dose 4D system performs automatic tube current modulation according to the patient's size and X-ray attenuation changes together with real-time tube current modulation during each tube rotation(8). The adaptation of the tube current is based on the user defined, image quality reference tube current-time product (mAs). The image quality reference mAs is expressed in terms of effective mAs, defined as mAs divided by the pitch. The reference value should be selected according to the diagnostic requirements and the individual preference of the radiologist. For different body regions (organ characteristic), a typical X-ray attenuation of a reference patient is internally stored with the related image quality reference mAs value. The reference patient is defined as a typical adult weighing 70-80 kg. In software versions prior to VA40, the paediatric protocols are based on a reference patient representing a typical child weighing 20 kg. The CARE Dose 4D lowers the tube current for slim patients or slim body parts of a patient and raises the tube current for obese patients or dense body parts of a patient. The basis for CARE Dose 4D is that different sized patients require different levels of noise to obtain an adequate image quality. Less noise is necessary in images of slim patients; whereas, more noise is often acceptable in obese patients because they contain more fat as an intrinsic contrast agent.(8,9) For each organ characteristic, the extent of change in the tube current can be controlled using five different adaptation strengths (very weak, weak, average, strong, or very strong)(10,11). In software versions prior to VA40, the adaptation strengths have a global effect on CARE Dose 4D and affect all scan protocols.

A single localizer is required to use CARE Dose 4D. The attenuation profile along the patient's long axis is measured in the direction of the X-ray projection and calculated for the perpendicular projection using a mathematical algorithm. If more than one localizer is acquired, all the information will be used. However, if there are localizers acquired from the same projection angle, only the most recent will be used. The angular modulation is based on attenuation profiles measured during each tube rotation and the tube current is modulated for the next rotation with a half rotation delay.(8)

Phantoms and the testing approach

Two anthropomorphic phantoms, an adult torso phantom (CTU-41, Kyoto Kagaku, Kyoto, Japan) and an adult chest phantom (PBU-X-21, Kyoto Kagaku, Kyoto, Japan), were examined using two different Siemens CT systems, the Definition Flash and Sensation 16 (Siemens Healthcare, Forchheim, Germany). The torso phantom corresponds to a male of approximately 60 kg and 165 cm. The chest phantom is based on the skeleton of a 160 cm tall male, of approximately 50 kg. The phantom materials and individual organs have CT numbers (Hounsfield unit) that corresponds to a human body and allow the simulation of a patient scan.

Examination parameters were chosen according to default settings from the manufacturer for a routine adult thorax examination (Table 1). To illustrate the importance of the localizer to the tube current modulation process, the following key aspects were investigated: the projection angle, patient centring, and scanning outside the localizer. In addition, the influences of the scanning direction, scan protocol (organ characteristic), and use of protective devices were evaluated.

To characterize the dynamics of the tube current modulation the mean effective mAs for each axial image was obtained from the digital imaging and communications in medicine (DICOM) image information. Evaluation of radiation dose in terms of the volume CT dose index ($CTDI_{vol}$) was obtained for each CT scan from the DICOM image information. The values of $CTDI_{vol}$ are referring to the average $CTDI_{vol}$ of the whole scan and are given for the 32 cm diameter CTDI phantom.

RESULTS

Projection angle of the localizer

When scanning the thorax region of the torso phantom on a Definition Flash system, changing from the default setting of single anterior-posterior (AP) localizer to single posterior-anterior (PA) localizer resulted in a 13% increase in the $CTDI_{vol}$. When performing both AP and lateral or PA and lateral localizers, the $CTDI_{vol}$ decreased by 20% compared with a single AP localizer. The dynamics of the tube current modulation for different tube projection angles of the localizer are shown in Figure 1.

Patient positioning and centring

The effect of patient centring on radiation dose was investigated by scanning the thorax region of the torso phantom on a Definition Flash system using different table heights. A single AP localizer was used for the tube current modulation. The dynamics of the tube current modulation for proper centred and ±5 cm off-centring table heights are shown in Figure 2. Increasing the height 5 cm above the gantry isocentre resulted in an 18% increase of $CTDI_{vol}$ and decreasing it 5 cm below the isocentre resulted in a 15% decrease of $CTDI_{vol}$.

The corresponding phantom acquisitions for different table heights were repeated, but both an AP and a lateral localizer were used for the tube current modulation. In this case, the $\mathrm{CTDI}_{\mathrm{vol}}$ increased by 1% when the table was raised 5 cm and decreased by 8% when the table was lowered 5 cm.

In addition to proper centring, it is important to position the patients correctly so that the entire region to be scanned is included on the localizer. The chest phantom was scanned on a Sensation 16 system outside the localizer range. Beyond the localizer, no tube current modulation was performed and the CARE Dose 4D adapted the tube current based on the closest available localizer information.

Protocol selection

The thorax region of the chest phantom was scanned on a Sensation 16 system with equal examination parameters using a thorax protocol and an abdomen protocol. The same AP localizer was used for both protocols. The $\mathrm{CTDI}_{\mathrm{vol}}$ was 18% lower using the abdomen protocol since the thickness of the reference patient's organ characteristic abdomen was greater than the organ characteristic thorax (Figure 3).

Scanning direction

The effects of scanning direction (craniocaudal versus caudocranial), when performing a thorax examination of the torso phantom on a Siemens Definition Flash, are shown in Figure 4. The angular tube current modulation is based on 180° pre-projection data, therefore, the dynamics of the tube current modulation are different. Scanning craniocaudal shows lower tube current in the upper chest region and consequently lower radiation dose to the breast. However, the $\mathrm{CTDI}_{\mathrm{vol}}$ were similar for the two scans.

Use of protective devices

The effect of using in-plane protective devices, such as bismuth organ shields, was evaluated by scanning the chest phantom on a Sensation 16 system (Figure 5). The adaptations of the tube current were similar for the scan when the breast shield was placed on the anterior surface of the phantom after the localizer was acquired and for the scan without any shield. When the breast shield was placed on the phantom prior to acquiring the localizer, the CARE Dose 4D system measured higher attenuation and the tube current was increased. The $\mathrm{CTDI}_{\mathrm{vol}}$ was increased by 14% compared with using no shield; thus, the dose reduction to the breast tissue from the bismuth shield was offset.

DISCUSSION

The AEC systems are an effective tool to reduce radiation exposure to patients undergoing CT examinations. Several clinical studies have shown patient dose reduction without compromising the diagnostic acceptability(12-14). However, for optimal use, there are several aspects of an AEC system that should be considered. The localizer is fundamental for an AEC system to obtain information on the patient's attenuation. The CARE Dose 4D system estimates the size, shape, and attenuation profile over the scan length from the localizer and it cannot be switched on without a localizer. As shown in this study, the tube projection angle of the localizer has a major impact on the radiation dose. A single PA localizer is associated with the highest radiation dose. The difference in radiation doses between a single AP and PA localizer may be a consequence of the table and the high attenuated spine of the phantom. When performing a PA localizer, the table and spine are closer to the X-ray tube and consequently magnified compared with an AP localizer. It is import that users are aware of this difference since there are publications that recommend performing a single PA localizer to reduce the radiation dose to anteriorly located tissues, such as the breasts and thyroid.

The lowest $\mathrm{CTDI}_{\mathrm{vol}}$ was obtained when two orthogonal localizers were acquired. This is in agreement with Singh et al.(15), who also showed that the order of two orthogonal localizers had no effect on radiation dose when using CARE Dose 4D. An additional benefit of acquiring two localizers is to ensure appropriate patient centring. However, when changing from the default single AP localizer setting to two orthogonal localizers, the image quality reference mAs may need to be increased to ensure diagnostic acceptability.

Inappropriate vertical centring of patients can increase both image noise and the radiation dose. For an adult CT scan of the thorax, 5 cm off-centring may result in an 18% increase of $\mathrm{CTDI}_{\mathrm{vol}}$. Patient attenuation is calculated from the localizer, assuming that the patient is positioned at the isocentre. Positioning above or below the isocentre affects the tube current modulation due to magnification and minification processes in the localizer views. The latest versions of Philips DoseRight and Toshiba SureExposure 3D will compensate for incorrect vertical patient positioning(16). However, in addition to correcting potential errors in the tube current calculation by the AEC system, a modern CT system uses beam-shaping (bowtie) filters to improve image uniformity and reduce the patient dose. Optimal functioning of the filters requires appropriate centring of the patients. Miscentring can increase the surface radiation dose and image noise and introduce artefacts(17). When two orthogonal localizers were acquired, a vertical miscentring of 5 cm had less effect on the tube current modulation ($\mathrm{CTDI}_{\mathrm{vol}}$ increased 1%) than using a single localizer. With two orthogonal localizers, CARE Dose 4D measures the attenuation profile in both directions instead of using a mathematical algorithm for calculating the attenuation profile in the perpendicular direction.

It is not only important to centre patients vertically but also to the left or right of the isocentre; otherwise, one side of the body will receive a higher radiation dose than the other. By using the position lights, the body's centre of gravity should be positioned in the scanner isocentre for optimal performance of the CARE Dose 4D system and for optimal overall image quality. Siemens does not recommend centring of the examined organ (e.g. the spine); although, there are exceptions, such as cardiac imaging. Due to the cardiac bowtie filter, the heart should be positioned close to the scanner isocentre.

In addition to proper positioning and centring of patients, it is important to include the entire region to be scanned in the localizer. No tube current modulation will occur beyond the localizer and CARE Dose 4D will adapt the tube current based on the closest available localizer information. The general recommendation is to be generous with the localizer, repeat if needed, and be sure all the anatomy to be covered is included(7). It is important to avoid repositioning of the patient and excessive motion between the localizer and CT scan. The arms should be in identical positions for the localizer and CT scan. Kuo et al.(18) highlights the importance of the arm position during the localizer to avoid increased radiation dose.

The adaptation of the tube current modulation using CARE Dose 4D is based on a typical X-ray attenuation of a reference patient that is stored for different body regions (organ characteristic). The thickness of the reference patient is 31.4 cm for a thorax protocol and 33.9 cm for an abdomen protocol. Consequently, when scanning the chest phantom, the $CTDI_{vol}$ was 18% lower using the abdomen protocol compared with the thorax protocol. To achieve optimal tube current modulation as well as minimize the radiation exposure and achieve optimal image quality, the scan protocol that fits to the anatomical region to be scanned should always be selected. For each organ characteristic, the extent of change in the tube current can be controlled using different adaptation strengths. Previous studies demonstrated that major user-specific modifications of image quality or radiation dose to the patient cohort can be obtained by selecting appropriate adaptation strengths(10,11).

The dynamics of the tube current modulation is dependent on the scanning direction since the online angular tube current modulation is based on 180° pre-projection data. The influence of scan direction on tube current modulation was studied in phantoms by Goo et al.(19), and they also showed differences in the modulated tube current between craniocaudal and caudocranial scans in regions with abrupt changes in size and/or attenuation. Wu et al.(19) studied respiratory motion artefacts from craniocaudal versus caudocranial scanning for CT pulmonary angiography. They concluded that, when using 64-slice technology with rapid acquisition, the scan direction didn't significantly affect the severity of the respiratory motion artefact. The opportunity to select the scanning direction helps to minimize the radiation exposure and achieve optimal image quality. In addition to scan direction, other factors such as the detector (beam) collimation and pitch have an effect on the angular tube current modulation. Using a narrow beam collimation and low pitch offers rapid adaptation of the tube current due to shorter longitudinal coverage per gantry rotation. However, the geometric efficiency and the radiation utilization decrease along with decreasing detector collimation due to imperfect collimation of the X-ray beam and movement of the X-ray focal spot.

When scanning metal implants, CARE Dose 4D tries to ignore the contribution of the high-attenuated material(5). For larger implants and when protective devices, such as organ shields are used, CARE Dose 4D will increase the tube current for the affected projections. To avoid an excessive increase in radiation dose, organ shields should be applied after the localizer. The American Association of Physicists in Medicine has made a statement on the use of bismuth shielding when using AEC systems(21). They recommend that other alternatives should be considered and implemented when possible due to the risk of potentially undesirable dose levels and image quality. Today, some CT manufacturers offer organ-based tube current modulation systems, e.g. the Siemens X-CARE. Wang et al.(22) showed that organ-based tube current modulation can achieve the same dose reduction as bismuth shielding without introducing artefacts, affecting the CT number accuracy, and increasing image noise.

A useful application connected to CARE Dose 4D is the Siemens CARE Profile, which visualizes the tube current modulation in the longitudinal direction for the planned examination after a localizer is performed. It also displays the minimum and maximum tube current, which could be useful for the user when a tube load conflict appears and a scan cannot be performed without changing parameters.

A limitation of this study is that the findings may not apply to AEC systems from other manufacturers. The characteristics of an AEC system are manufacturer-specific and they are continuously developing their systems. Therefore, education and good communication between the manufacturers and users are very important. Another limitation of this study is that image quality has not been evaluated. The aim was to discuss and illustrate several aspects of an AEC system that need to be considered for optimal outcome. The findings in this study are valid for the anthropomorphic phantoms used, which both simulates a slim adult patient with average anatomical characteristics. The results may potentially differ when real patients with varying anatomy are examined.

CONCLUSION

When optimizing the CT radiation dose and image quality, there are several aspects of the AEC system to consider: the projection angle of the localizer, patient positioning and centring, protocol selection, scanning direction, and use of protective devices.

TABLES

Table 1. Examination parameters used for phantom measurements.

Phantom	Torso CTU-41	Chest PBU-X-21
System	Siemens Definition Flash	Siemens Sensation 16
Scan mode	Spiral	Spiral
Detector configuration	128×0.6	16×1.5
Nominal beam width (mm)	38.4	24
Tube voltage (kV)	120	120
Quality reference effective mAs	65	100
Rotation time (s)	0.5	0.5
Pitch	1.2	1.15
Slice thickness (mm)	5	5
Adaptation strengths	Average /average	Strong /weak
Software version	VA40A	VA10A

FIGURE LEGENDS

Figure 1. Effective mAs per slice along the longitudinal axis of the torso phantom using different tube projection angles of the localizer. Data are overlaid on the anterior-posterior localizer. The volume CT dose index for each scan is shown in parenthesis.

Figure 2. Effective mAs per slice along the longitudinal axis of the torso phantom for different table heights. Data are overlaid on the anterior-posterior localizer. The volume CT dose index for each scan is presented in parenthesis.

Figure 3. Effective mAs per slice along the longitudinal axis of the chest phantom using a thorax or an abdomen protocol. Data are overlaid on the anterior-posterior localizer. The volume CT dose index for each scan is presented in parenthesis.

Figure 4. Effective mAs per slice along the longitudinal axis of the torso phantom when scanning in craniocaudal direction or caudocranial direction. Data are overlaid on the anterior-posterior localizer. The volume CT dose index for each scan is presented in parenthesis.

Figure 5. Effective mAs per slice along the longitudinal axis of the chest phantom before and after using the bismuth shielding. Data are overlaid on the anterior-posterior localizer obtained with a bismuth shield on the phantom. The volume CT dose index for each scan is presented in parenthesis.

Figure 1.

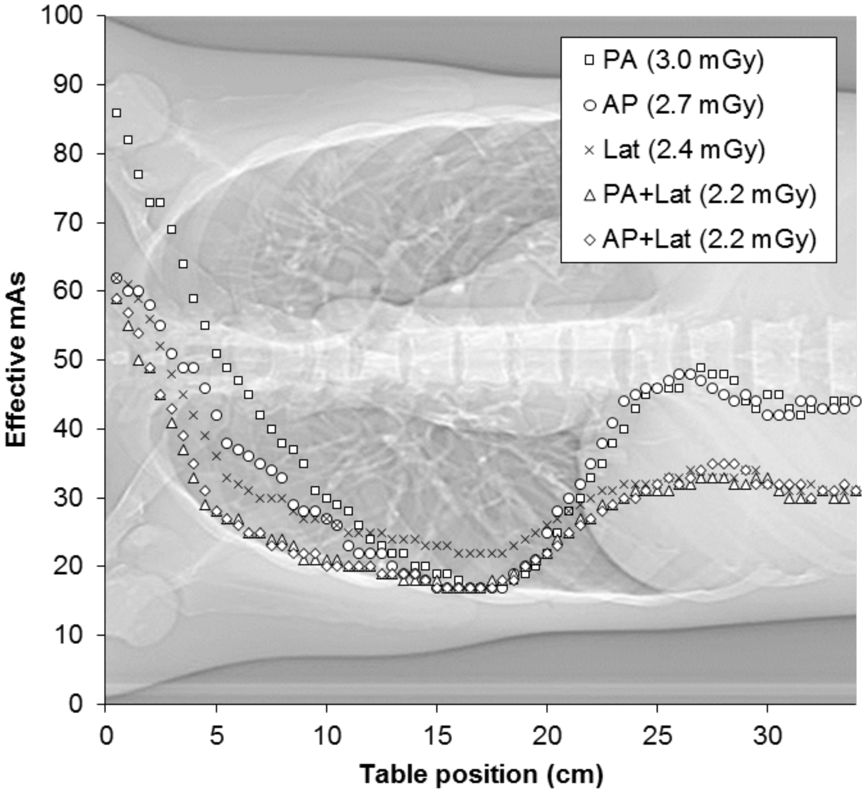
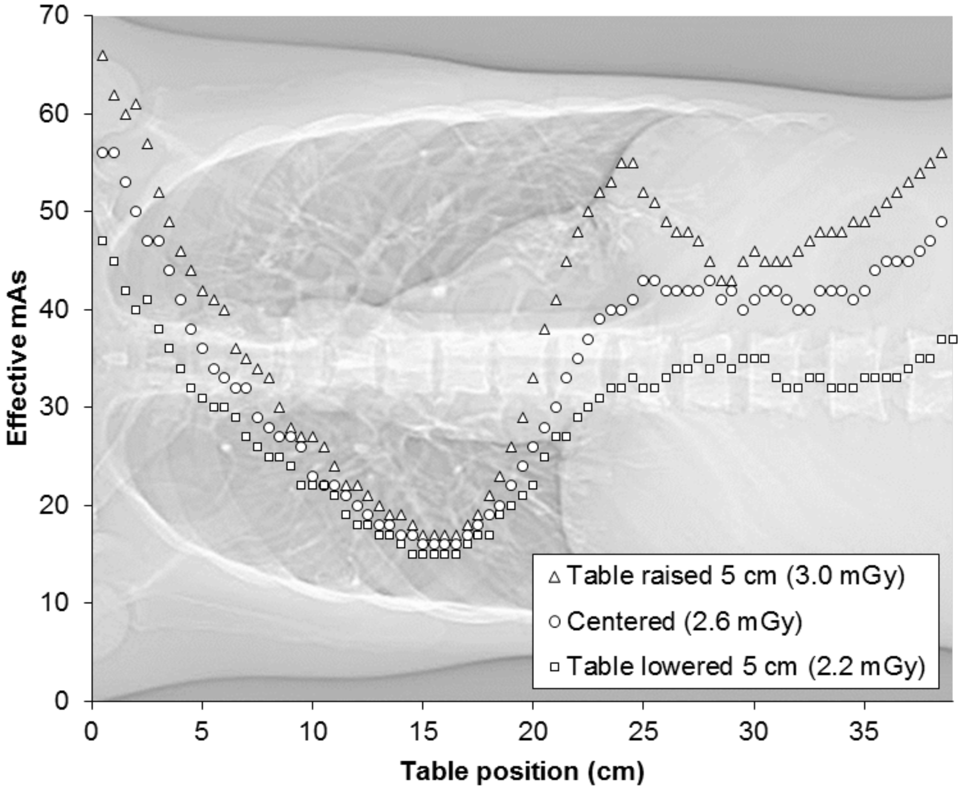
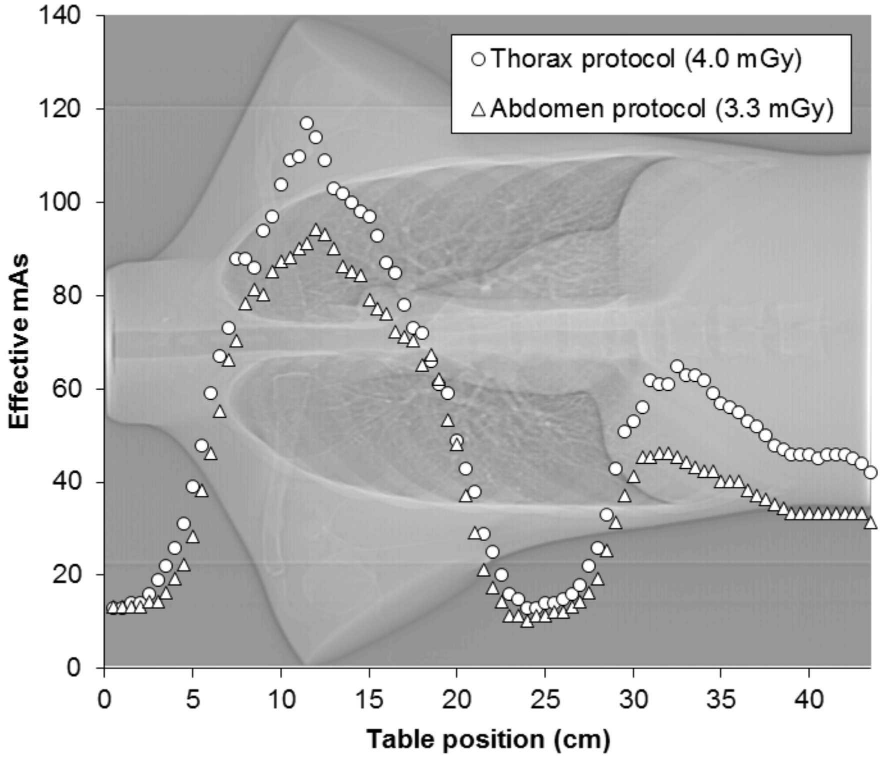

Effective mAs
Table position (cm)
0
10
20
30
40
50
60
70
80
90
100
0
5
10
15
20
25
30
□ PA (3.0 mGy)
○ AP (2.7 mGy)
× Lat (2.4 mGy)
△ PA+Lat (2.2 mGy)
◇ AP+Lat (2.2 mGy)

Figure 2.



Effective mAs
Table position (cm)
0
10
20
30
40
50
60
70
0
5
10
15
20
25
30
35
△ Table raised 5 cm (3.0 mGy)
○ Centered (2.6 mGy)
□ Table lowered 5 cm (2.2 mGy)

Figure 3.



140
120
100
80
60
40
20
0
Effective mAs
0
5
10
15
20
25
30
35
40
Table position (cm)
○ Thorax protocol (4.0 mGy)
△ Abdomen protocol (3.3 mGy)

Figure 4.

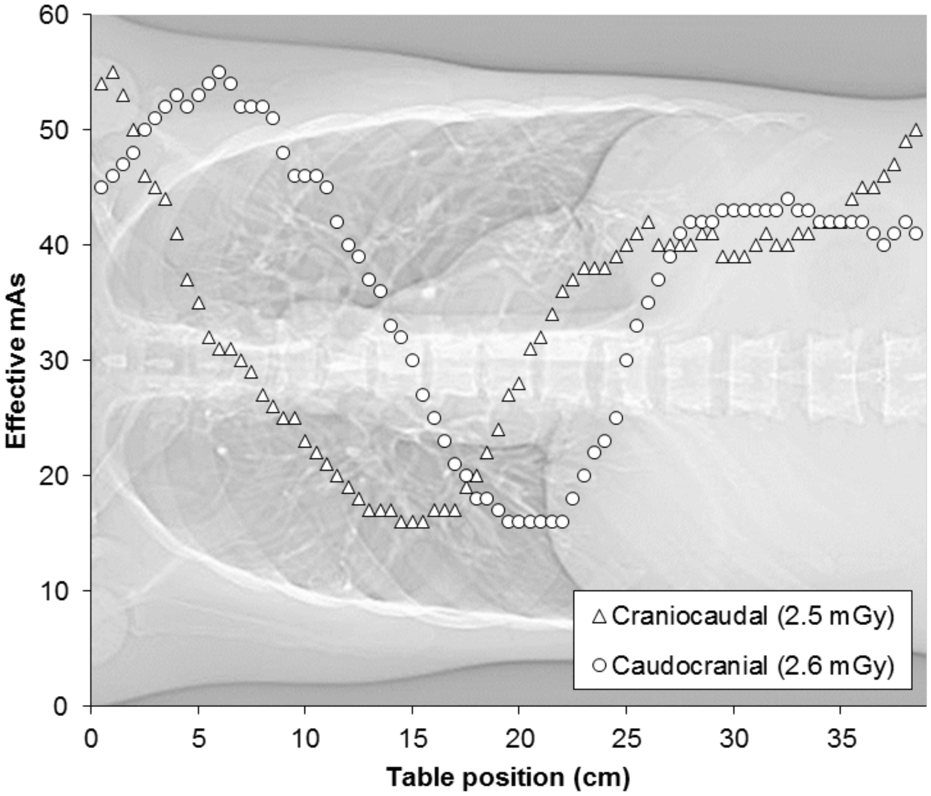
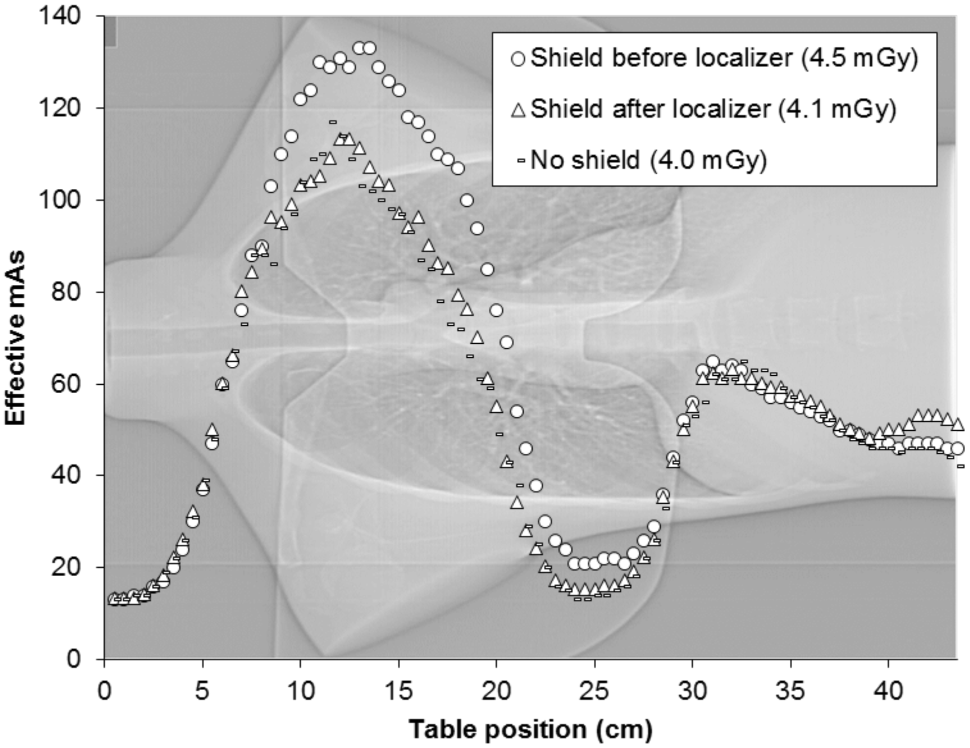

Effective mAs
60
50
40
30
20
10
0
0
5
10
15
20
25
30
35
Table position (cm)
△ Craniocaudal (2.5 mGy)
○ Caudocranial (2.6 mGy)

Figure 5.



○ Shield before localizer (4.5 mGy)
△ Shield after localizer (4.1 mGy)
▭ No shield (4.0 mGy)
Effective mAs
Table position (cm)
0
20
40
60
80
100
120
140
0
5
10
15
20
25
30
35
40

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