CARE Dose4D CT Automatic Exposure Control System: *Physics Principles and Practical Hints*

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Introduction to CT Automatic Exposure Control (AEC)

Why use AEC in CT?

The use of ionizing radiation for medically appropriate imaging procedures far outweighs the small increase in risk. However, prudence demands that users and manufacturers take all reasonable steps to decrease the radiation dose to the patient, especially considering the continued increase in the use of medical imaging. One of the most important technologies used to reduce dose in CT is AEC, which aims to automatically modulate the tube current to compensate for variations in patient attenuation, both between different patients and within any given patient.

Within any given patient, there can be strong variations in x-ray attenuation as the tube rotates around the patient, particularly in anatomic regions that are very elliptical in shape, such as the thorax and pelvis. The use of a constant tube current causes the x-ray projections through the most attenuating view angles to primarily determine the noise level in the reconstructed cross sectional image. The projections through less attenuated view angles deliver radiation that contributes to the overall radiation dose, but does not further improve the quality of the final image. Angular tube current modulation allows the scanner to modify the current in real-time, based upon the attenuation at any given projection angle, such that similar noise can be maintained regardless of the projection angle. Angular tube current modulation can provide a dose reduction of 40-50% without compromising image quality.

The same concept can be used to adapt the tube current to different anatomic regions and to varied patient sizes in order to produce consistent image quality at the lowest achievable dose. For smaller patients, less tube current, and therefore less dose, is needed to obtain the desired image quality. Larger patients require an increase in tube current to achieve diagnostic image quality, with a necessary increase in the delivered radiation dose. AEC has become a standard dose reduction and image quality tool and is offered in various forms by all major CT manufacturers.

Effective use of this important dose management tool requires an understanding of the AEC system implemented by the manufacturer. The four major AEC schemes are summarized in Table I, according to manufacturer.

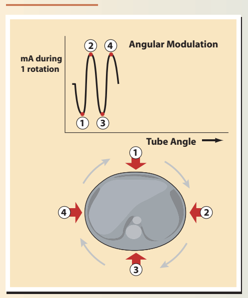
Table I: Summary of the four most common AEC strategies

Manufacturer	AEC Trade name	Image Quality Reference	Goal
General Electric	Auto mA, Smart mA	Noise Index	Constant image noise regardless of attenuation level, using tube currents within prescribed minimum and maximum values.
Toshiba	SureExposure	Target Image Quality Level	
Siemens	CARE Dose4D	Quality Reference Effective mAs	Constant image quality regardless of attenuation level, with reference to a target mAs level for a standard-sized patient.
Philips	DoseRight	Reference Image	Keep the same image quality as in the reference image, regardless of attenuation level.

AEC Basic Principles

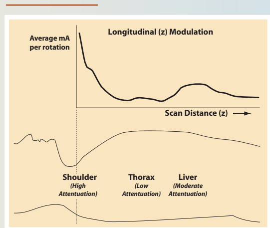
AEC is a generic name for any technique aimed at optimizing dose utilization by adjusting the tube current in real-time to accommodate differences in attenuation due to patient anatomy, shape, and size. The tube current may be modulated as a function of projection angle (Fig. 1a), longitudinal location along the patients (Fig. 1b), or both (Fig. 1c).

FIGURE 1a



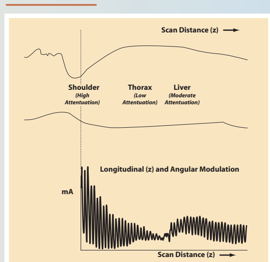
Angular tube current modulation

FIGURE 1b



Longitudinal tube current modulation

FIGURE 1c



Longitudinal and Angular tube current modulation

Purpose

The purpose of this exhibit is to extend this basic description of AEC, providing an explanation of the principles of operation for one specific system (CARE Dose4D, Siemens Medical Solutions). The objective is to equip CT operators with the information needed to optimally use this AEC system effectively in both routine and challenging clinical situations.

How CARE Dose4D Works

CARE Dose4D terminology

Topogram: The name used on Siemens' CT equipment for the scanned projection radiograph. This low dose, projection image is used to localize the start and end locations of a scan. In CARE Dose4D, the topogram is also used to determine the attenuation levels of the patient. Only one topogram is required (either AP or lateral); the perpendicular view is estimated using a mathematical model.

Effective mAs: This technique parameter equals the actual tube current–time product (mAs) divided by the spiral pitch value. In CARE Dose4D, this value is automatically determined by the system according to the selected Quality Reference mAs (QRM), the topogram, and the selected scan protocol. After the topogram has been acquired, the estimated average effective mAs that will be used during the scan is displayed, which may be larger or smaller than the prescribed QRM. After the scan, this value is updated to the actual average effective mAs used for the scan acquisition, which may vary slightly from the average effective mAs displayed before the scan because CARE Dose4D updates the pre-scan estimated values with more accurate values determined during the actual scan acquisition.

Quality Reference mAs (QRM): The technique parameter entered by the user to determine the desired level of image quality. The QRM is expressed in terms of effective mAs. The QRM is set equal to the effective mAs that produces the desired image quality on a standard-sized patient. During the scan, the tube current (and therefore the effective mAs) is automatically adjusted to compensate for variations in patient size and attenuation, thereby providing image quality consistent with that obtained using the QRM level for a standard-sized patient, but appropriate to both smaller or larger patients.

Base Protocol: A scan protocol available on the scanner that was created by the manufacturer. In addition to the user-selectable scan parameters, a base protocol contains information relating to the anatomical structures within the expected scan range and their corresponding reference attenuation values. This information cannot be viewed or edited by the user. Different base protocols are available for adult and pediatric scans. All user scan protocols are created by modifying a base protocol.

CARE Dose4D principles

CARE Dose4D performs automatic tube-current modulation in the angular and longitudinal directions and also adapts to different anatomical regions and patient sizes.

The first step in using CARE Dose4D is to acquire a topogram of the patient, which the software will use to determine the required tube current for each projection of the entire scan. Based upon the topogram data, the attenuation for one projection (e.g. PA) is measured and the attenuation for the complementary projection (e.g. lateral) is calculated with consideration given to the patient girth and anatomic region (head, thorax, pelvis, etc.).

Next, the user checks the CARE Dose4D box in the selected scan of the protocol. Marking this box disables the manual effective mAs entry and allows a value to be entered into the QRM field. The CARE Dose4D software then calculates the estimated *optimal* tube current for every angular projection. The generator/tube load and system limits are also considered to ensure appropriate tube capacity through out the scan.

Finally, during the scan, CARE Dose4D will perform on-line attenuation-based tube current-modulation. This fine-tunes the predicted *optimal* tube current values (estimated from the topogram data) according to the actual attenuation measured 180 degrees earlier in the tube rotation. This allows the system to adapt to temporally varying levels of attenuation, such as from the injection of contrast media or due to patient motion between the topogram and actual scan acquisition, as well as to optimally modulate tube current in extremely elliptical regions, such as the shoulders. The on-line feedback system reads the transmission values at a given angle and uses that information to predict the optimal tube current for the projection that will occur 180 degrees later in the tube rotation. The system lowers the tube current through areas of the body that have a decreased attenuation relative to the "reference attenuation level" of a standard-sized patient and raises the tube current where the anatomy is more attenuating. Figure 2 shows the measured attenuation and calculated tube current for a scan of the chest, abdomen and pelvis. The algorithm for calculating the required tube current is graphically described in Figure 3 and the configuration menu for altering the strength of the tube current modulation is shown in Figure 4.

FIGURE 2

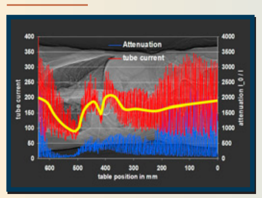


Figure 2: On-line attenuation-based tube current modulation. The topogram is initially used for estimating the attenuation levels along the PA and lateral directions of the patient and predicting the required tube current for each table position. During each tube rotation of the acquisition, real-time feedback determines higher-order corrections to the estimated tube current for each subsequent rotation. The blue curve represents the attenuation level measured from the on-line feedback system for each table position. The red curve represents the tube current for each table position calculated based upon the attenuation level at that projection angle. The yellow curve represents the average tube current over 360 degrees, which is used to calculate the effective mAs that is displayed on each reconstructed image slice after the acquisition is complete.

FIGURE 3

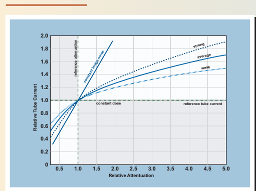


Figure 3: Graphical description of the algorithm used to calculate the required tube current. The horizontal axis represents the attenuation level relative to a reference attenuation level (1.0). The vertical axis represents the modulated tube current relative to a reference tube current (1.0, corresponding to the QRM prescribed by the operator). The four blue curves represent four modulation strengths. The straight line yields constant image noise, which reaches the maximum allowable tube current for attenuation values that are only moderately larger that the reference — this method is not used by CARE Dose4D. The other three curves represent the three different strengths of tube current modulation (strong, average, weak) allowed by CARE Dose4D. The strength is an operator configurable parameter on the scanner.

FIGURE 4

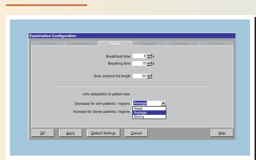


Figure 4: Modulation strength setting Each scanner is globally configurable to a particular modulation strength (strong, average, or weak) for both slim patients/thin regions and obese patients/thick regions. This setting has a global effect on the operation of CARE Dose4D for the scanner and is not protocol specific.

Important considerations in the Clinical Use of CARE Dose4D

Topogram

- The topogram is used by CARE Dose4D to determine the appropriate tube current.
- If a topogram is unavailable, CARE Dose4D cannot be used.
- If the scan length extends beyond the range included in the topogram, CARE Dose4D will use the value of the effective mAs for the closest region included in the topogram.
- Ideally, the kV used to acquire the scan should match that used to acquire the topogram. If the scan is acquired at a different kV than the topogram, the dose optimization may be slightly affected but the overall quality of the exam will not be jeopardized. There is no need to repeat a topogram that was acquired at 120 kV if the scan requires 140 kV, or visa versa.
- Positioning the patient at isocenter is essential! Otherwise, the attenuation calculated based upon an off-centered topogram will not be accurate. If a patient is centered too low and the tube is positioned under the table (Fig. 5a), the patient appears wider on the topogram than he/she actually is (Fig. 5b), thus misinforming the CARE Dose4D algorithm regarding the patient width. Similarly, centering too high will misinform CARE Dose4D as to the patient size (Fig. 5c).

  Note: Images in Figure 5 were simulated for demonstration purposes.

FIGURE 5a

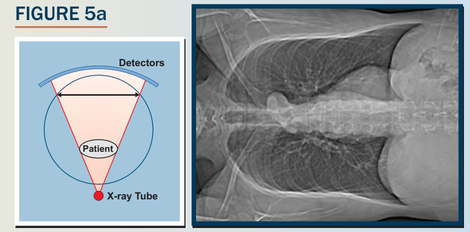


Figure 5a: Patient is centered too low in the scan field, making the patient appear wider than he/she actually is. The resultant exam may use more dose than is necessary.

FIGURE 5b

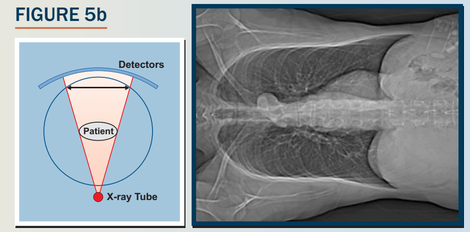


Figure 5b: Patient is properly centered in the scan field. Note that the tube is positioned under the table in Figures 5a–c.

FIGURE 5c

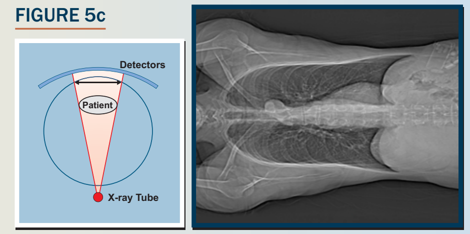


Figure 5c: Patient is centered too high in the scan field, making the patient appear narrower than he/she actually is. The resultant images may be too noisy.

Base protocol:

- Each body part has its own reference attenuation value and default modulation type.
- The base protocol provides information to the scanner regarding the expected body part to be imaged.
- From this information, the reference attenuation level and default modulation type (angular, longitudinal, or both) are prescribed by the scanner. Adult protocols are based upon a standard 75 kg adult and pediatric protocols are based upon a 20 kg child (typical of a 5-year-old). For pediatric body exams, select a pediatric base protocol for those patients weighing 55kg or less. An adult base protocol should be used for patients weighing greater than 55kg. Neuro exams are based on the age of the patient. Select the pediatric base protocol for patients age six and under. Use the adult base protocol for patients older than six. CARE Dose4D will decrease the tube current appropriately from the adult reference values, according to the patient size.
- It is essential to design site-specific protocols using the correct base protocol. The selected base protocol not only affects dose utilization, but can also affect the availability of other scan parameters, such as kernel and kV options.
- When the patient size falls in between adult and pediatric sizes, the base protocol (adult or child) is not critical—the image quality resulting from the tube current modulation at the transitional sizes is very similar as long as the QRM of the pediatric or adult protocol is chosen appropriately.

QRM and Tube Capacity:

The maximum tube current achieved during modulation is limited by the tube and generator capacity. As patient size or attenuation increases, the scanner will increase the tube current and may reach the limit of the system (Figure 6). If the estimated required tube current for an acquisition exceeds the system limit at any location within the scan length, a warning message will be presented to the user (Figure 7). This message must be addressed before the user can proceed to acquire the scan.

FIGURE 6

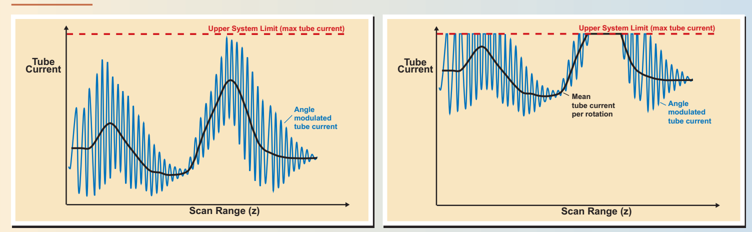


Figure 6: (a) Tube current modulation as a function of angle and z position. All desired values fall below the maximum tube current of the system. (b) If the desired tube current exceeds the system limit at any location, the tube current will be restricted to the maximum allowable limit. The user will be informed that the image quality may be decreased locally (i.e. in some regions, see Fig. 7). The operator must decide if such limitation is acceptable or else alter the scan parameters such that the system can accommodate all desired tube current values.

Clinical Tips and Tricks

Large patients

Large patients require a significant increase in tube current, which may exceed the maximum value available for a given configurations of kV, rotation time and pitch. In this situation, a warning dialog box (Fig. 7) will appear indicating that at some point in the scan, the system will need more tube current than is allowed. The user has the option of continuing with the current settings, which may or may not produce an optimal image, or to cancel the acquisition. Cancelling this message allows the user to modify the scan parameters such that the scan can proceed without any potential compromise in image quality. This warning message only appears when CARE Dose4D is on.

Options for increasing the dose in spite of the system tube current limitation include:

- ***Decrease the pitch.***
  - This will increase the number of photons per slice without affecting the reconstructed slice thickness, at the expense of increased scan time.
- ***Switch to a larger total collimation and then decrease pitch.***
  - This will provide a larger longitudinal coverage for each rotation, decreasing the total scan time. The pitch can then be decreased to increase the number of photons per slice (see above). However, using a larger collimation will increase the thinnest reconstructed slice thickness that is available.
- ***Change from 120 kV to 140 kV.***
  - This improves x-ray penetration and tube output. Image contrast will be lowered somewhat and the QRM will need to be adjusted (downward) to compensate for the increase in kV.
- ***Increase the rotation time.***
  - This will allow more photons per rotation. Scan times will be increased.

FIGURE 7

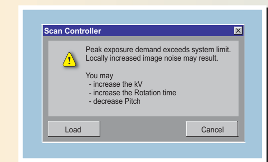


Figure 7: Warning dialogue box that is presented to the user when any desired tube current exceeds the system limit.

Patients with metallic implants

Metallic implants, which can cause strong artifacts in the form of dark or bright streaks (Fig. 8), are not uncommon in patients receiving CT examinations. They occur when an insufficient number of photons reach the detector, having been highly attenuated by the dense metal. For larger implants, CARE Dose4D will slightly increase the tube current for the affected projections. As shown in Fig. 8, with an implant (Fig. 8a), the average effective tube current/rotation (blue curve, Fig. 8c) increases in the region over the metal compared to when the metal has been removed (Figure 8b), where the average effective tube current/rotation (pink curve, Fig. 8c) is slowly reduced over the same region. This demonstrates that CARE Dose4D attempts to reduce the streaking artifact caused by the metal by increasing the tube current over the implant. To avoid an excessive increase in dose, which will not fully resolve the metal artifacts, the tube current is not maximized over the entire implant, increasing only a moderate amount. The tube current is not increased for small metal objects, which cause minimal streak artifacts.

The following actions may help to improve image quality in patients with metallic implants:

- ***Use 140 kV.***
  - Higher kV images may have less metal artifacts due to reduced beam hardening and decreased attenuation through the implant.
- ***Use a longer rotation time and smaller spiral pitch, consistent with the scan indication.***
  - This will provide more dose through the implant when CARE Dose4D increases the tube current to the system limit.
- ***Appropriately increase the QRM.***
  - A larger tube current will, in some cases, reduce the streaking artifacts to a more acceptable level. It is important to note that increasing the tube current will not completely eliminate the streaking artifact and will always increase patient radiation dose.
- ***Check with the manufacture to see if metal artifact reduction software is available.***

FIGURE 8

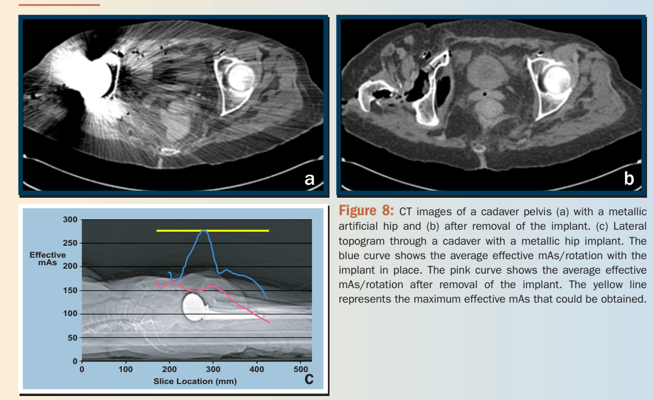


Figure 8: CT images of a cadaver pelvis (a) with a metallic artificial hip and (b) after removal of the implant. (c) Lateral topogram through a cadaver with a metallic hip implant. The blue curve shows the average effective mAs/rotation with the implant in place. The pink curve shows the average effective mAs/rotation after removal of the implant. The yellow line represents the maximum effective mAs that could be obtained.