Automatic Exposure Control in CT: Applications and Limitations

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Tube current (mA) is one of the key technical scanning parameters for adjusting radiation dose in CT. To optimize radiation dose in CT, users can adjust mA either with manually selected mA values or with the application of automatic exposure control (AEC). The latter technique refers to automatic adaptation of mA on the basis of user-specified image quality and x-ray attenuation characteristics of the scanned body region [1-4].

TYPES OF AUTOMATIC EXPOSURE CONTROL

Automatic exposure control can adapt mA at different spatial projections (spatial mA modulation) or at specified time points of an electrocardiographically gated CT protocol (temporal mA modulation). The latter technique is used primarily for coronary CT angiography and is the subject of a subsequent article dealing with cardiac CT radiation dose.

Most modern multiple-detector row CT scanners use up to 3 major types of spatial mA modulation techniques (Table 1). The angular, x-y, or transverse modulation technique adjusts mA at different projections (positions of the x-ray tube in relation to the patient) within each gantry rotation [1]. The x-y modulation techniques determine cross-sectional attenuation characteristics of the body region being scanned from either localizer radiographs or the initial one-half gantry rotation of the x-ray tube. Because image noise is governed by the attenuation of x-rays from the projections with greatest attenuation, the technique reduces mA in other projections associated with lower x-ray attenuation. For example, at the level of the shoulders, the greatest attenuation occurs in the lateral projection, which allows the technique to reduce mA in other projections while maintaining constant noise compared to a single fixed mA. In generic terms, to apply x-y modulation, users specify mA just as they would for fixed-mA examination and turn on the x-y modulation feature on the scanner user interface.

Longitudinal or z modulation uses localizer radiographs to determine attenuation characteristics at different scanning positions along patient length (z axis) (Figure 1). On the basis of user-specified image quality metric and body region-specific attenuation characteristics, mA is increased at z-axis positions with greater attenuation (such as in the pelvis from bony structures) and decreased for lower attenuation regions (such as in the middle abdomen, with more soft tissues). To apply these techniques, users must first understand and then select an image quality metric (such as noise index, standard deviation, mA-time product (mAs)/slice, or reference mAs) specific to desired diagnostic information.

As implied by its name, the combined or x-y-z modulation technique combines the x-y and z modulation techniques to adjust mA values in all 3 axes on the basis of attenuation characteristics of the scanned body region and user-specified image quality. Compared with the use of the individual x-y or z modulation technique, x-y-z modulation techniques generally allow greater dose reduction on the basis of cross-sectional asymmetry as well as longitudinal variations in attenuation along the body region being scanned. Most x-y-z modulation techniques require estimation of regional attenuation characteristics from localizer radiographs, with one vendor technique (CARE Dose 4D; Siemens Medical Systems, Erlangen, Germany) obtaining information for x-y modulation from the initial one-half gantry rotation. Like the z-modulation technique, this technique also requires users to specify an image quality metric.

APPLICATION OF AUTOMATIC EXPOSURE CONTROL TECHNIQUES

Automatic exposure control techniques are available on most multidetector CT scanners from major vendors (Table 1). To apply these techniques, users specify a desired image quality in terms of image noise (noise index: Auto mA, GE Healthcare, Milwaukee, Wisconsin; standard deviation: Sure Exposure, Toshiba Medical Systems, Tokyo, Japan) or mAs for a reference adult or pediatric patient (reference mAs: CARE Dose 4D; mAs/slice: Z-DOM, Philips Medical Systems, Andover, Massachusetts) (Table 2) [1-4].

Although most AEC techniques are based on similar physics principles, there are some differences in features of the AEC techniques from different vendors. Some vendors allow users to specify an mA range within which dose modula-

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Table 1. AEC techniques currently available from different vendors

AEC Technique	GE Healthcare	Siemens	Philips	Toshiba
x-y axis/angular	Smart mA	CARE Dose	D-DOM	—
z axis/longitudinal	Auto mA	ZEC	Z-DOM	SureExposure
x-y-z/combined	Auto mA 3D	CARE Dose 4D	—	SureExposure3D

Note: AEC = automatic exposure control.

tion is desired. Another vendor allows control of the strength of modulation for patients who are smaller or larger than the "reference patient."

Contrary to fixed mA, whereby users specify mA settings for different patient sizes and clinical indications, AEC requires user-defined adjustment for different clinical indications and automatically adapts mA for different patient sizes. Furthermore, most AEC techniques are programmed to maintain similar radiation dose with changes in scanning parameters such as slice thickness, pitch, and applied kilovoltage [3,4].

From a practical standpoint, when switching to AEC from fixed mA, it is important to separate adult and pediatric protocols. Because children are at greater risk for radiation induced adverse effects and are scanned for different clinical indications than adults, lower dose settings of AEC should be used for children. Within individual body regions, AEC settings should then be set for individual groups of clinical indications. This process is aided by first setting the AEC parameters for "routine or general" scanning protocols and then modifying the settings to reduce or increase radiation dose for specific clinical indications. For example, for abdominal CT, lower dose AEC settings must be used for kidney stone and CT colonography protocols compared with a "routine or general" abdominal CT protocol. On the other hand, AEC settings can be adjusted to deliver better image quality in subjects undergoing a pancreatic or hepatic malignancy CT protocol.

Prior studies have documented substantial CT radiation dose reductions in the head, neck, chest, and abdomen with use of AEC in adult as well as pediatric patients [5]. For head CT, z modulation decreases dose by 35% compared with the use of fixed mA [6,7]. In adult patients, different AEC techniques have been shown to reduce radiation dose by 14% to 38% for chest CT [8-10] and by 20% to 35% for abdominal CT [8,10,11]. Substantial dose reductions with AEC techniques have also been reported for CT of the neck, pelvis, elbow, and lower extremities [8,10]. Singh et al [12] reported 50% to 75% dose reduction with an x-y-z modulation technique stratified for different clinical indications in chest and abdomen CT in children.

To maintain constant image quality, AEC techniques increase radiation dose for large or obese patients in relation to smaller or average size patients. Although such an increase in radiation dose in large patients may be desirable in low-contrast lesions in the liver or pan-

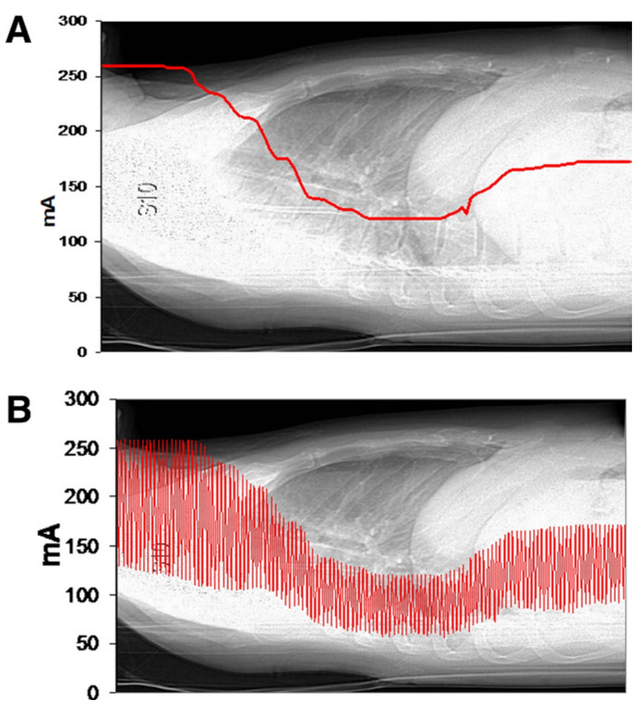

Fig 1. Graphical representation of tube current (mA) modulation in chest CT. Longitudinal modulation of mA is characterized by change in mA at different slice positions on the basis of change in attenuation of the body region along the patient's length (A). In combined modulation, angular modulation is added to the longitudinal modulation (B) to adapt mA within each slice position on the basis of the cross-sectional asymmetry of body region being scanned.

Table 2. Different methods chosen by manufacturers to optimize mA by setting exposure level

Technique	Specified Parameter	Implications
Auto mA 3D (GE Healthcare)	Noise index	Implies user-desired noise in the entire image
	Minimum and maximum mA	Range of allowed mA to achieve desired noise index
	Smart mA	Selection of this optional function adds x-y modulation to z modulation (Auto mA)
CARE Dose 4D (Siemens)	Reference mAs	Implies need for image quality equal to that obtained with the use of specified reference mAs in a standard adult (70-80 kg) or child (20 kg)
Z-DOM (Philips)	Baseline mAs	"Baseline mAs" is used as a reference to obtain constant image noise along the z axis
SureExposure 3D (Toshiba)	Standard deviation	Implies need for obtaining images at specified image noise (standard deviation)

Note: mA = tube current; mAs = tube current-time product.

creas, in other instances, such as for chest or kidney stone evaluation, such an increase in radiation dose may not be necessary. Therefore, if image quality requirements with AEC are set at an inappropriately high setting, larger patients will receive excessive radiation dose. In the same context, certain AEC techniques require modification in specified image quality metric with change in parameters such as pitch, reconstructed slice thickness, and kernels (such as noise index and standard deviation), whereas others require no such modification for maintaining constant radiation dose. Users must make themselves familiar with these aspects of AEC techniques. A thorough review of published literature and user manuals for recommended settings for use of AEC is especially useful.

AUTOMATIC EXPOSURE CONTROL CAVEATS

Users employing equipment from different vendors must understand that there are marked differences in nomenclature associated with implementation of AEC techniques on different multidetector CT scanners (Table 1). Although AEC techniques represent one of the most important implementation techniques for dose optimization purposes, there are several caveats and limitations associated with implementation of these techniques. Knowledge of these considerations should help and encourage users to enhance AEC implementation.

Because most AEC techniques use localizer radiographs for mA modulation, localizer radiographs must include the entire region being scanned; no mA modulation occurs beyond the localizer radiograph. It is also important to instruct patients to avoid voluntary movements after the acquisition of localizer radiographs and before initiating scanning.

Most CT scanners now use beam-shaping filters to reduce radiation dose and homogenize image quality. These filters require appropriate centering of patients for optimum functioning. Inappropriate off-centering of patients scanned with AEC techniques can increase image noise and the surface radiation dose as well as lead to potential errors in mA calculations by the AEC techniques. Careful attention to patient centering is especially important for small children or small adults when using AEC techniques.

Another consideration with AEC techniques is the position of patients' arms for acquisition of localizer radiographs as well as transverse images. When possible for chest and abdominal CT, patients' arms must be positioned out of the field of view for both localizer and transverse images. Positioning of the arms along the chest or abdomen increases regional attenuation and thus increases applied mA with use of AEC techniques. In patients who cannot or should not raise their arms out of the body region being scanned, users can either allow the system to increase radiation dose to avoid excessive image noise or decrease the settings of AEC techniques to reduce radiation dose on the basis of requirements of diagnostic information [13]. When concomitant neck and chest CT scanning is required, either 2 separate localizers and scanning series can be performed or a single localizer with the arms by the side of the neck can be acquired for a "single-run" neck and chest CT study.

Users must also understand behavior of AEC techniques on their individual scanners in regions with large metallic prosthesis. Although some techniques (such as CARE Dose 4D) ignore the contribution of high-attenuation metallic prosthesis when estimating required mA, others (such as Auto mA) increase mA in the presence of large metallic implants without a noticeable decrease in beam hardening or streak artifacts [14]. Users should not apply the latter group of AEC techniques when metallic implants are likely to represent a major portion of body region being scanned.

When ultra-low-dose CT images acquired at substantially low or lowest allowed mA are feasible for certain body regions or clinical indications, manual selection of low or lowest fixed mA may be sufficient, advantageous, and easier to implement. At Massachusetts General Hospital, we use very low fixed mA (20-60 mAs) to acquire very low-dose CT for body regions and clinical indications such as follow-up of lung nodules, lung cancer screening, colonography, paranasal sinuses, and bones of the extremities.

Things to keep in mind to avoid caveats and limitations and to enhance the use of AEC include the following:

1. Patient centering to the CT gantry is important, especially when scanning children and small adults.
2. Performing appropriate localizer scans while scanning multiple regions (neck, chest, and abdomen) is necessary to avoid inappropriate operation of AEC.
3. It is necessary to understand how AEC techniques handle large metallic prostheses and make corresponding changes (as this can vary among manufacturers).
4. For low-dose screening protocols, the best option is to set mA manually to ensure low-dose scanning. (Figure 1).

REFERENCES

1. Kalra MK, Maher MM, Toth TL, et al. Techniques and applications of automatic tube current modulation for CT. Radiology 2004;233:649-57.
2. McCollough CH, Bruesewitz MR, Kofler JM Jr. CT dose reduction and dose management tools: overview of available options. Radiographics 2006;26:503-12.
3. Mahesh M. MDCT physics: the basics—technology, image quality and radiation dose. Philadelphia: Lippincott Williams & Wilkins; 2009.
4. Keat N. CT scanner automatic exposure control systems (report 05016). Available at: http://www.impactscan.org/reports/Report05016. Accessed February 2, 2011.
5. Greess H, Nömayr A, Wolf H, et al. Dose reduction in CT examination of children by an attenuation-based on-line modulation of tube current (CARE Dose). Eur Radiol 2002;12:1571-6.
6. Namasivayam S, Kalra MK, Pottala KM, Waldrop SM, Hudgins PA. Optimization of Z-axis automatic exposure control for multidetector row CT evaluation of neck and comparison with fixed tube current technique for image quality and radiation dose. AJNR Am J Neuroradiol 2006;27:2221-5.
7. Russell MT, Fink JR, Rebeles F, Kanal K, Ramos M, Anzai Y. Balancing radiation dose and image quality: clinical applications of neck volume CT. AJNR Am J Neuroradiol 2008;29:727-31.
8. Mulkens TH, Bellinck P, Baeyaert M, et al. Use of an automatic exposure control mechanism for dose optimization in multi-detector row CT examinations: clinical evaluation. Radiology 2005;237:213-23.
9. Kalra MK, Rizzo S, Maher MM, et al. Chest CT performed with z-axis modulation: scanning protocol and radiation dose. Radiology 2005;237:303-8.
10. Greess H, Wolf H, Baum U, et al. Dose reduction in computed tomography by attenuation-based on-line modulation of tube current: evaluation of six anatomical regions. Eur Radiol 2000;10:391-4.
11. Kalra MK, Maher MM, Kamath RS, et al. Sixteen-detector row CT of abdomen and pelvis: study for optimization of Z-axis modulation technique performed in 153 patients. Radiology 2004;233:241-9.
12. Singh S, Kalra MK, Moore MA, et al. Dose reduction and compliance with pediatric CT protocols adapted to patient size, clinical indication, and number of prior studies. Radiology 2009;252:200-8.
13. Kalra MK, Maher MM, Saini S. What is the optimum position of arms for acquiring scout images for whole-body CT with automatic tube current modulation? AJR Am J Roentgenol 2003;181:596-7.
14. Dalal T, Kalra MK, Rizzo SM, Schmidt B, Suess C, Flohr T, Blake MA, Saini S. Metallic prosthesis: technique to avoid increase in CT radiation dose with automatic tube current modulation in a phantom and patients. Radiology 2005;236:671-5.

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