Balancing Radiation Dose and Image Quality: Clinical Applications of Neck Volume CT

BACKGROUND AND PURPOSE: The advancement of multidetector CT technology has resulted in improved image quality as well as an increase in ionizing radiation dose to patient. The purpose of this study was to assess radiation dose and overall image quality of CT examination of the neck between fixed-tube current and automatic tube current modulation (ATCM) at 2 separate noise index levels.

MATERIALS AND METHODS: A total of 84 patients underwent neck CT with use of a 64-section multidetector row CT (MDCT) scanner. Patients were divided into 3 groups: fixed-tube current (n = 28), ATCM with a noise index of 11.4 (n = 28), and ATCM with a noise index of 20.2 (n = 28). All other scan parameters remained constant. Scan coverage length and transclavicular distance were measured. Two radiologists blinded to the scanning parameters assessed overall image quality, noise level, and streak artifacts using a 5-point grading scale. The radiation dose in dose-length product (DLP) and CT dose index (CTDI) was recorded.

RESULTS: Compared with a fixed-tube current technique, ATCM with a noise index of 11.4 reduced CTDI by 20% (P < .01 × 10⁻¹²), and ATCM with a noise index of 20.2 reduced CTDI by 34% (P < .01 × 10⁻¹⁴). Although the difference in image quality between the fixed-tube current technique and the noise index reachd statistical significance (P < .05), the magnitude of the difference was small, with average scores of 3.79 (±0.59) and 3.57 (±0.53), respectively.

CONCLUSION: Compared with the fixed-tube current technique, ATCM resulted in significant reduction of radiation dose without substantially reducing the image quality of the CT of the neck. Judicious monitoring of radiation dose to patients has to be balanced with diagnostic image quality.
versity of Washington with either fixed mA or ATCM techniques using 2 predetermined noise index values: 11.4 and 20.2. The noise index value is specified by the vendor as “approximately equal to standard deviation in the central region of the image when a uniform phantom is scanned and reconstructed.”

The other scanning parameters remained constant for each patient, regardless of the technique. These scanning parameters were 140 kVp, pitch 0.987, gantry rotation time 0.5 second, beam collimation 40 mm, FOV 20 cm, 2.5-mm reconstructed section thickness, and a standard reconstruction algorithm. In addition to these parameters, fixed mA values between 400 and 650 mA and an auto mA range of 100 to 750 mA with a noise index of 11.4 and 20.2 were used. Intravenous contrast material (100–150 mL Optiray; Mallinkrodt, Hazelwood, Mo) was injected through an antecubital vein, and scanning was initiated after a 100-second delay.

Radiation Dose
Radiation “exposure” is usually a measured quantity, whereas the absorbed radiation “dose” is typically a value calculated from the exposure and from estimates of energy absorbed per body mass unit. The fundamental radiation dose parameter in CT is the CT dose index (CTDI). The volume CTDI (CTDIvol), a derivative of the CTDI (mGy), can be used to express the average dose delivered to the scan volume for a specific examination. CTDIvol is considered more useful than the dose-length product (DLP), body weight or shoulder width was not measured routinely for the radiation dose for a specific CT examination because its numeric value is affected by variance in patient anatomy such as the patient’s height. In this study, we recorded both CTDIvol and DLP for each subject.

Subject Size and Scan Length
Although the size and height of the subject influence radiation dose (DLP), body weight or shoulder width was not measured routinely for patients who underwent CT of the neck. Because the shoulder width seems to be a reasonable surrogate of patients’ body size, we measured the transclavicular length (measurement taken from the sternal notch, paralleling the clavicle, extending out to the skin marking just below the acromioclavicular joint) on the scout view. In addition, we also measured the total scan length of the neck CT (from the skull base to the superior part of the mediastinum) using the table positions by subtracting the table position of the lowest section from the highest tube current technique.

Statistical Analysis
The unpaired t test (Excel 2004, version 11.2.5; Microsoft, Redmond, Wash) was used to compare average transclavicular distance, scan length, DLP, and CTDIvol with 3 different imaging techniques. The Wilcoxon Mann-Whitney nonparametric test (STATA SE 8.0; StataCorp, College Station, Tex) was used to compare overall quality, image noise, and streak artifacts in each examination performed with the 3 different noise index values. The readers independently graded the quality of each image on a 5-point grading scale. Two board certified neuroradiologists (J.R.F. and F.R.) blinded to the imaging technique independently reviewed the 2.5-mm reconstructed axial images on PACS. We facilitated the blinding by removing the scanning parameters from the PACS screen. The readers independently graded the studies for overall image quality, noise (mottle, graininess), and streak artifacts using a 5-point grading scale.

Results
There was no significant difference in transclavicular distance or scan coverage length among the 3 groups, indicating that subjects were similar in body size and scan volume.

There was a substantially significant difference in radiation dose among the 3 groups, with a DLP of 1179 ± 109 (mGy-cm) for fixed mA, 925 ± 116 for ATCM with a noise index of 11.4, and 729 ± 148 for ATCM with a noise index of 11.4 and 779 ± 148 for ATCM with a noise index of 20.2 (Table 1). Compared with fixed-tube current, an overall reduction of 22% in DLP was achieved with the use of ATCM with a noise index of 11.4 (P < .001 × 10⁻³) and an overall reduction of 38% in DLP with ATCM with a noise index of 20.2 (P < .001 × 10⁻¹¹). There was also a 21% reduction in DLP with use of a noise index of 20.2 compared with a noise index of 20.2, which determined the number of subjects for each technique. We consecutively reviewed cases with fixed mA and noise index 11.4 techniques from the same study period, then eliminating patients with transclavicular distances of more than 24 cm or less than 17 cm as well as cases with scan lengths of more than 400 cm or less than 200 cm. One patient with noise index 11.4 did not have a radiation dose record for unknown reasons; thus, this patient was eliminated from the study. This resulted in 28 patients with fixed mA and 28 patients with noise index 11.4 techniques.

There were 12 female and 16 male subjects with a mean age of 52 years (range, 23–81 years) for a noise index of 20.2; 8 female and 20 male subjects with a mean age of 49 years (range, 20–82 years) for a noise index of 11.4, and 7 female and 21 male subjects with a mean age of 49 years (range, 20–71 years) for fixed mA.
Table 1: Summary of transclavicular distance, scan length, dose-length product (DLP), and CT dose index (CTDI)

| Measurement     | Transclavicular Distance (cm) | Scan Length (cm) | DLP (mGy-cm) | CTDI (mGy) |
|-----------------|-------------------------------|------------------|--------------|------------|
| Fixed mA        | 20.1 ± 1.3                    | 30.1 ± 2.5       | 1179 ± 109   | 34.7 ± 2.2 |
| NI 11.4         | 20.1 ± 1.5                    | 30.1 ± 2.7       | 925 ± 116    | 27.8 ± 3.5 |
| NI 20.2         | 19.8 ± 1.5                    | 29.4 ± 4.4       | 729 ± 148    | 23.0 ± 3.5 |

Note: —NI indicates noise index; mA, tube current-time product.

Table 2: P values of Student t test between two different imaging techniques

| Measurement     | Transclavicular Distance | Scan Length | DLP          | CTDI          |
|-----------------|--------------------------|-------------|--------------|---------------|
| Fixed mA vs NI 11.4 | 0.46                     | 0.43        | <0.008 × 10⁻⁷ | <0.008 × 10⁻⁶ |
| NI 11.4 vs NI 20.2 | 0.92                     | 0.89        | <0.001 × 10⁻³ | <0.0001      |
| Fixed mA vs NI 20.2 | 0.43                     | 0.42        | <0.007 × 10⁻¹¹ | <0.004 × 10⁻¹² |

Note: —NI indicates noise index; DLP, dose-length product; CTDI, CT dose index; mA, tube current-time product.

Discussion

In this preliminary analysis, we found a significant reduction in radiation dose with the use of ATCM compared with a fixed mA technique for volume neck CT. Although there was a small difference in pooled subjective scores on image quality and noise, the magnitude of the difference was small. CT examination of the neck with the use of the ATCM technique with a noise index of 11.4 and 20.2 provides image quality that is diagnostically acceptable. Therefore, in keeping with the ALARA concept, we endorse the use of ATCM with a noise index of 20.2 for MDCT of the neck.

ATCM was developed to minimize subjective estimation and selection of tube current required to obtain desired image quality.²⁻⁴ Shortly after installation of 64-section MDCT at our institution, the fixed mA technique was used exclusively. The tube current in this setting was manually selected by CT technologists by subjective estimation of patients’ body size, often resulting in inconsistent image quality. The neck was an ideal body part in which to use combination ATCM because of its widely varying shape and attenuation within the subject and the presence of highly radiosensitive organs (ie, thyroid and lens) in CT examinations of the neck. To the best of our knowledge, there is no previously published data evaluating the use of combination ATCM (z-axis and angular modulation) in neck CT. These findings are in agreement with previously published reports regarding CT of the chest, abdomen, and pelvis with use of ATCM.⁶⁻¹¹

In August 2001, the Society of Pediatric Radiology organized a multidisciplinary ALARA conference in that the consensus was a statistically significant, albeit small, individual risk for excess cancer in children from ionizing doses of radiation used in helical CT. On the basis of new and more extensive data, the Committee on the Biologic Effects of Ionizing Radiation VII supported a “linear-no-threshold” model, which states that the risk for cancer in humans proceeds in a linear fashion at lower doses without a “safe” threshold, and that even the smallest dose has the potential to cause a small increase in risk to humans.¹³

Although reduction in radiation dose is an important exercise, maintaining high quality of a diagnostic imaging study is also essential to provide an accurate and definitive diagnosis. We must keep a fine balance between image quality and radiation dose. One could argue that radiation exposure from a diagnostic CT imaging scan is relatively small for patients with head and neck cancer who undergo therapeutic irradiation,
compared with young patients who are suspect for infectious or inflammatory disease. Imaging techniques such as noise index can be potentially tailored to individual patient needs and risks in the future.

Limitations of this study were the small sample size and the retrospective collection of study materials, which might have introduced selection bias. In addition, further investigation needs to be performed to better define an “acceptable” image quality for head and neck radiologists. Blinded assessment of image quality may not be the most robust measures of image quality. Moreover, accuracy or conspicuity of abnormality was not addressed in this study. The ultimate threshold between acceptable and unacceptable imaging quality might be defined as a noise index high enough to start missing an abnormal lesion. This is not practical to investigate in the clinical setting. It is highly
likely that acceptable image quality could vary depending on individual radiologists.

Patient safety and quality of care have been discussed extensively in health care organizations including the Centers for Medicare & Medicaid. One of the important quality metrics in diagnostic radiology is radiation dose.14 Judicious monitoring of radiation dose to patients is highly essential to ensure patient safety, and such efforts have to be balanced with diagnostic quality of imaging examinations.

Conclusions
ATCM technique substantially reduced radiation dose to patients without significantly compromising image quality of 64-section MDCT of the neck. The neck is an ideal body part to apply ATCM because of its widely varying shape and attenuation within a subject and the presence of highly radiosensitive organs (ie, thyroid and lens). With the ALARA concept, institutional effort of balancing image quality and radiation dose to patients is essential for providing high quality of clinical care and patient safety.

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