Radiation Dose-Reduction Strategies for Neuroradiology CT Protocols

A.B. Smith, W.P. Dillon, R. Gould and M. Wintermark

*AJNR Am J Neuroradiol* 2007, 28 (9) 1628-1632
doi: https://doi.org/10.3174/ajnr.A0814
http://www.ajnr.org/content/28/9/1628

This information is current as of February 24, 2024.
The increase in the number of CT studies in the United States and Europe\textsuperscript{1,2} that followed the introduction of multidetector-row technology has led to a significant increase in the radiation dose related to CT scanning.\textsuperscript{3-6} CT scanning comprises approximately 15\% of radiologic examinations but represents the largest single source of medical radiation exposure, accounting for up to 70\% of the radiation dose to patients.\textsuperscript{7} Patients are becoming more aware of the radiation dose related to CT scanning due to increasing coverage in the lay press.\textsuperscript{8} The radiation risk to children is of particular concern; the estimated lifetime cancer risk for a 1-year-old child from the radiation exposure of a head CT is 0.07\%.\textsuperscript{9}

The potential health risks associated with radiation have placed increasing pressure on the radiology community to ensure that CT imaging protocols are optimized for diagnostic image quality at the lowest radiation dose possible (“as low as reasonably achievable”). Because the latest generation of CT scanners automatically records the CT dose for each study and archives this as part of the patient’s permanent medical record, exaggerated delays in implementing dose-reduction strategies may also have medical-legal implications. The purpose of this review is to discuss available methods to achieve dose reduction for neuroradiology CT protocols while preserving the diagnostic quality of imaging studies.

CT-Associated Radiation-Dose Measurement

In 2001, in response to the growing concern over CT-associated radiation dose, the US Food and Drug Administration published guidelines to address this issue, especially in pediatric patients and in the small-adult population. These guidelines give recommendations on how to optimize CT protocols and encourage the elimination of inappropriate referrals for CT as well as the reduction of the number of unnecessary repeat examinations.\textsuperscript{10} Along the same lines, the American College of Radiology (ACR) established a voluntary CT accreditation program. Institutions that apply are invited to complete a series of protocols and to submit patient and phantom images, along with dose measurements, to show that they abide by ACR dose recommendations.\textsuperscript{11}

To understand the radiation dose a patient receives for a particular scan, one must have knowledge of the methods of dose measurement. Multiple dose descriptors have been used in the past. Currently, the Computed Tomography Dose Index (CTDI), along with its variants, and the Dose Length Product (DLP) are the standard parameters used to describe CT-associated radiation dose.

Different versions of the CTDI have been used. Historically, the CTDI was initially defined as the radiation dose measured from 14 contiguous sections and normalized to beam width and beam current. To account for the radiation dose delivered both within and beyond the scanning volume. Indeed, scattered radiation, divergence of radiation beam, and limits in efficiency of beam collimation result in the radiation delivered during a CT scan not fully contained within the scanning volume. The CTDI\textsubscript{100} was developed to address the limitation of the 14-section model and allowed calculation of the index for 100 mm along the length of a pencil ionization chamber. The weighted CTDI (CTDIw) was subsequently developed to overcome the limitations of dependency on position within the scanning plane. CTDIw describes the average dose delivered within a 100-mm-diameter circular phantom, adding up the central dose weighted by a one-third factor and the peripheral dose weighted by a two-thirds factor. The most recent and presently used version is the volumetric CTDI (CTDI\textsubscript{vol}), which was introduced to take into account the pitch of helical acquisition. The CTDI\textsubscript{vol} represents the average dose delivered within the reconstructed section and is calculated as the CTDI\textsubscript{w} divided by the pitch.\textsuperscript{12,13}

The DLP is the CTDI\textsubscript{vol} multiplied by the scanning length expressed in centimeters. It gives an indication of the energy imparted to organs and can be used to assess overall radiation burden associated with a CT study. CT scanners now routinely record the CTDI\textsubscript{vol} and, in some cases, the DLP. Although the

**SUMMARY:** Within the past 2 decades, the number of CT examinations performed has increased almost 10-fold. This is in large part due to advances in multidetector-row CT technology, which now allows faster image acquisition and improved isotropic imaging. The increased use, along with multidetector technique, has led to a significantly increased radiation dose to the patient from CT studies. This places increased responsibility on the radiologist to ensure that CT examinations are indicated and that the “as low as reasonably achievable” concept is adhered to. Neuroradiologists are familiar with factors that affect patient dose such as pitch, milliamperes, kilovolt peak (kVp), collimation, but with increasing attention being given to dose reduction, they are looking for additional ways to further reduce the radiation associated with their CT protocols. In response to increasing concern, CT manufacturers have developed dose-reduction tools, such as dose modulation, in which the tube current is adjusted along with the CT acquisition, according to patient’s attenuation. This review will describe the available techniques for reducing dose associated with neuroradiologic CT imaging protocols.
CTDI_{vol} is not the dose to a specific patient, it is an index of the average radiation dose from the different CT series.\textsuperscript{1,12,13}

The ACR guidelines set reference values for CTDI on the basis of reports from the American Association of Physicists in Medicine and the International Commission on Radiologic Protection. For instance, for a head CT in an adult patient, the recommended CTDI_{L} is 60 mGy. If this dose is exceeded, measures need to be taken to reduce the patient dose.\textsuperscript{11}

**CT Acquisition Parameters and Dose Reduction**

The setting of CT parameters such as tube current, tube rotation time, peak voltage, pitch, and collimation is a major contributor to the radiation dose received during a CT study. Typically, if one of these parameters is decreased, another needs to be increased to maintain image quality. Developing methods for dose reduction for CT protocols consequently takes a team effort of physicist, radiologist, and technician to determine the best compromise between diagnostic image quality and radiation dose.\textsuperscript{14}

The initial approach to optimizing dose is to determine what information is desired from an examination and the associated minimum level of contrast to noise that is acceptable for diagnostic purposes. If lesser contrast is required and greater noise can be tolerated, then a lower tube current (and lower milliamperes) should be used. Tube current is directly proportional to dose; therefore, tube current reduction will result in a lower dose but at a cost of increased noise, which is increased by 1/\sqrt{\text{mA}}. Gantry rotation time also has a similar effect on radiation dosage, and reducing the gantry rotation time by half leads to the same results in dose as reducing the milliamperes by half. This can be advantageous when a quicker acquisition is needed, for instance in unstable patients.\textsuperscript{14} Of note, decreasing the gantry rotation time is not a panacea because it may unfavorably impact on the spatial resolution. Indeed, as explained previously, decreasing the gantry rotation time has to be compensated by an increase in milliamperes to maintain the milliamperes at a constant level. Increasing the milliamperes above a certain value (300–350) will typically result in the CT scanner switching from the small to the large detector.\textsuperscript{1}

As a general rule of the thumb, collimation should be set to acquire images as thin as one may be interested (now or later), but realizing the potential cost in dose. Typically, thin collimation (0.625 mm) and thin (and overlapped) reconstructions (0.625 mm) are used for those techniques that require high spatial detail, such as intracranial CTA or CT of the cervical spine, where the highest spatial resolution is sought to detect small aneurysms or subtle fractures. At the other end of the spectrum, thin collimation (0.625 mm) and thicker reconstruction (and again overlapped) images (2.5 mm) may be best used for CT studies of the lumbar spine. This “acquire thin and view thick” strategy is very dose-efficient because whereas the display images will be thick, low acquisition parameters can be used for the acquisition. The source images will be noisy, but the thick images used for review will not; and the source images with higher spatial resolution will be available if required to interpret an unresolved finding on the thick review images and as source images for 2D and 3D reformats. This “acquire thin and review thick” approach is not only efficient in terms of radiation dose but also improves workflow because fewer images need to be reviewed.

**CT Dose Modulation**

Many of the dose-reduction strategies described previously result in a trade-off of image quality. For example, if tube current or voltage is reduced, the radiation dose is reduced, but so is image quality. CT manufacturers have tried to come up with new technologies that can reduce dose without significantly compromising imaging quality. One of these techniques is dose modulation.

Dose modulation is a technique by which the CT scanner modifies the tube current in response to the patient’s atten-
atation, to maintain the same image quality for the least possible tube current. Dose modulation can be performed in the z-axis where tube current changes along the length of the patient, in the xy-plane (angular modification), or can be a combination of the 2 (xyz–dose modulation). Recent studies demonstrated that dose modulation is capable of providing a reduction in radiation dose without significant image compromise,\textsuperscript{16–20} including for neuroradiology CT protocols, where up to 60% dose reduction was achieved for noncontrast CT of the brain in adult and pediatric patients; for CT studies of the cervical spine; and for CTA studies.\textsuperscript{21}

Implementation of dose modulation requires a team effort between radiologists, technicians, and physicists, who have to select a preset noise index (NI) that describes the level of noise acceptable to the radiologist for a given CT examination. The CT scanner then automatically selects, within a preset range, the tube current (milliampere) required to maintain the level of noise under the noise index, taking into consideration the patient’s attenuation. Identification of optimal signal intensity-to-noise ratio for each type of CT protocol requires fine-tuning to lower the milliamperes as much as possible while preserving image quality. When we transitioned to dose modulation, we initially set the NI at a low value (as recommended by the manufacturer) and progressively increased it until the image quality was deemed insufficient. This decision was a consensus decision by the 9 faculty members of our neuroradiology section.

**Image Postprocessing as an Additional Consideration for Dose Reduction**

Isotropic resolution afforded by modern multidetector row CT scanners allows high-quality image reconstruction and can help diminish the number of scans needed, thus reducing patient dose. Previously, we used to acquire both axial and direct coronal images for our sinus CT studies. We now acquire the coronal images for our sinus CT studies. We now acquire the coronal images for our sinus CT studies.

Dose Reduction

Image Postprocessing as an Additional Consideration for Dose Reduction

Isotropic resolution afforded by modern multidetector row CT scanners allows high-quality image reconstruction and can help diminish the number of scans needed, thus reducing patient dose. Previously, we used to acquire both axial and direct coronal images for our sinus CT studies. We now acquire the coronal images for our sinus CT studies. However, we have to select a preset noise index (NI) that describes the level of noise acceptable to the radiologist for a given CT examination. The CT scanner then automatically selects, within a preset range, the tube current (milliampere) required to maintain the level of noise under the noise index, taking into consideration the patient’s attenuation. Identification of optimal signal intensity-to-noise ratio for each type of CT protocol requires fine-tuning to lower the milliamperes as much as possible while preserving image quality. When we transitioned to dose modulation, we initially set the NI at a low value (as recommended by the manufacturer) and progressively increased it until the image quality was deemed insufficient. This decision was a consensus decision by the 9 faculty members of our neuroradiology section.

**Conclusion**

CT scanners are a major contributor to the radiation dose received in radiology departments. There are many strategies available to reduce the radiation dose associated with neuroradiology CT protocols. Some of these strategies involve changes in the acquisition parameters (kVp, gantry rotation time, milliampere, pitch). Such strategies, however, always involve a compromise between image quality and radiation dose. The optimal compromise can usually be achieved by applying simple rules of thumb (such as “acquire thin and review thick”). More recently, CT manufacturers have introduced techniques of dose reduction, such as dose modulation, which result in a decrease in dose to patients without significant image compromise. As such, we recommend the systematic implementation of dose modulation for all neuroradiology CT protocols.

**Appendix**

In this appendix are listed our neuroradiology CT protocols for our 64-section CT scanners (Lightspeed VCT; GE Healthcare, Milwaukee, Wis). These are to serve as an illustration of...
Subarachnoid hemorrhage and venous thrombosis CT protocols*

<table>
<thead>
<tr>
<th>Series</th>
<th>Type</th>
<th>FOV (cm) kVp</th>
<th>Auto mA</th>
<th>Rotation Time</th>
<th>Section Thickness</th>
<th>Reconstruction Interval</th>
<th>Prep Group</th>
<th>Amount</th>
<th>Saline Flush</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>NCT</td>
<td>Helical</td>
<td>32 × 0.625</td>
<td>0.969:1</td>
<td>19.37</td>
<td>22 120 100 350 4</td>
<td>1 2.5</td>
<td>2.5</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>PCT1</td>
<td>Cine</td>
<td>8 × 5</td>
<td>– –</td>
<td>22 80 100</td>
<td>1 5 5</td>
<td>7 40 25 5</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>PCT2</td>
<td>Cine</td>
<td>8 × 5</td>
<td>– –</td>
<td>22 80 100</td>
<td>1 5 5</td>
<td>7 40 25 5</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>CTA</td>
<td>Helical</td>
<td>64 × 0.625</td>
<td>0.984:1</td>
<td>98.42</td>
<td>25 120 200 400 12</td>
<td>0.4 0.625</td>
<td>0.5 From PCT</td>
<td>70</td>
<td>25 5</td>
<td>–</td>
</tr>
<tr>
<td>CECT</td>
<td>Helical</td>
<td>32 × 0.625</td>
<td>0.969:1</td>
<td>19.37</td>
<td>22 120 100 350 4</td>
<td>1 2.5 2.5</td>
<td>120</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

Note: — Min, minimum; Max, maximum; –, not applicable.

* For subarachnoid hemorrhage CT Protocol: CTA prep group = PCT1 timing of the arterial peak + 7 seconds for venous thrombosis CT protocol: CTA prep group = PCT1 timing of the arterial peak + 10 seconds.

PCT1, above the orbits; PCT2, immediately adjacent to PCT1.

Orbit, face, and sinus CT protocols

<table>
<thead>
<tr>
<th>Series</th>
<th>Type</th>
<th>FOV (cm) kVp</th>
<th>Auto mA</th>
<th>Rotation Time</th>
<th>Section Thickness</th>
<th>Reconstruction Interval</th>
<th>Prep Group</th>
<th>Amount</th>
<th>Saline Flush</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Helical</td>
<td>64 × 0.625</td>
<td>0.984:1</td>
<td>49.21</td>
<td>18 120 100 200 12</td>
<td>0.8 1.25</td>
<td>1 –</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
</tbody>
</table>

Note: — Min, minimum; Max, maximum; –, not applicable.

Temporal bone CT protocol

<table>
<thead>
<tr>
<th>Series</th>
<th>Type</th>
<th>FOV (cm) kVp</th>
<th>Auto mA</th>
<th>Rotation Time</th>
<th>Section Thickness</th>
<th>Reconstruction Interval</th>
<th>Prep Group</th>
<th>Amount</th>
<th>Saline Flush</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Helical</td>
<td>64 × 0.625</td>
<td>0.984:1</td>
<td>49.21</td>
<td>20 120 100 200 9</td>
<td>0.8 0.625</td>
<td>0.5 –</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
</tbody>
</table>

Note: — Min, minimum; Max, maximum; –, not applicable.

Neck CT protocol

<table>
<thead>
<tr>
<th>Series</th>
<th>Type</th>
<th>FOV (cm) kVp</th>
<th>Auto mA</th>
<th>Rotation Time</th>
<th>Section Thickness</th>
<th>Reconstruction Interval</th>
<th>Prep Group</th>
<th>Amount</th>
<th>Saline Flush</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Helical</td>
<td>64 × 0.625</td>
<td>0.984:1</td>
<td>49.21</td>
<td>18 120 100 200 6</td>
<td>0.8 2.5</td>
<td>2</td>
<td>60</td>
<td>100</td>
<td>25</td>
<td>2</td>
</tr>
</tbody>
</table>

Note: — Min, minimum; Max, maximum.

Cervical spine CT protocol

<table>
<thead>
<tr>
<th>Series</th>
<th>Type</th>
<th>FOV (cm) kVp</th>
<th>Auto mA</th>
<th>Rotation Time</th>
<th>Section Thickness</th>
<th>Reconstruction Interval</th>
<th>Prep Group</th>
<th>Amount</th>
<th>Saline Flush</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Helical</td>
<td>64 × 0.625</td>
<td>0.984:1</td>
<td>49.21</td>
<td>18 120 100 200 9</td>
<td>0.8 0.625</td>
<td>0.5 –</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
</tbody>
</table>

Note: — Min, minimum; Max, maximum; –, not applicable.

Thoracic and lumbar spine CT protocol

<table>
<thead>
<tr>
<th>Series</th>
<th>Type</th>
<th>FOV (cm) kVp</th>
<th>Auto mA</th>
<th>Rotation Time</th>
<th>Section Thickness</th>
<th>Reconstruction Interval</th>
<th>Prep Group</th>
<th>Amount</th>
<th>Saline Flush</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Helical</td>
<td>64 × 0.625</td>
<td>1.375:1</td>
<td>68.75</td>
<td>18 120 150 250 12</td>
<td>0.8 2.5</td>
<td>2</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

Note: — Min, minimum; Max, maximum; –, not applicable.

our dose-reduction strategies described in the body of the review.

References