Direct measurement of CTDI\(_w\) on helical CT scans

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Abstract

**Purpose:** Medical physics computed tomography (CT) practice involves measurements to determine CTDI\(_{vol}\) on representative clinical CT protocols. In current practice the majority of CT exams employ helical scans. To determine CTDI\(_{vol}\) for a helical scan, one measures CTDI\(_w\) with an axial scan, then divides by the pitch. Problems arise in CT units where one is unable to select an axial scan with the same detector configuration and pre-patient (bowtie) filtration that is employed on the helical scan. Presented is a method to measure CTDI\(_w\) on helical scans.

**Methods:** The body and head CTDI phantoms were supported on the gantry shroud with brackets attached to the phantom. The phantom is above the tabletop and remains stationary during helical scans as the table moves beneath the phantom. With the phantom stationary, the CTDI\(_w\) associated with head and body helical scans was measured. CTDI\(_w\) was also measured for head and body axial scans with the same pre-patient filtrations and detector configurations.

**Results:** For both the head and body CTDI phantom the agreement between the axial and helical CTDI\(_w\) measurements was \(<1.5\%\).

**Conclusions:** Body and head CTDI\(_w\) and CTDI\(_{vol}\) can be directly measured by employing helical scans with the method in this paper.

**KEYWORDS**
computed tomography, CTDI, CTDI\(_w\) helical acquisition

1 | INTRODUCTION

Volumetric computed tomography dose index or CTDI\(_{vol}\) is routinely determined by medical physicists for clinical scan protocols during CT scanner acceptance testing, annual performance audits, and ACR CT Accreditation submission data acquisition.\(^1,2\) This is accomplished by centering the CTDI phantom in the CT gantry, measuring CTDI\(_w\) with an axial scan (keeping the phantom stationary), and dividing by the pitch.

In present day clinical practice, many, if not the majority, of the CT exams employ helical scan protocols. On some CT scanners, for example, Siemens Force and Drive models, axial scans with the same detector configuration and pre-patient filtration (bowtie filter) employed on helical protocols are not available. Measuring CTDI\(_w\) and determining CTDI\(_{vol}\) on these scanners is problematic. One approach to the problem is to obtain a service key from the manufacturer which permits one to make the desired axial scans and measure the CTDI\(_w\) associated with the helical scan protocol of interest. However, service keys are difficult to obtain, and are not always available. Obtaining service keys is also not feasible for the consulting medical physicist who has a number of different scanners to support and a limited time window to make his/her measurements.

An alternative approach to the problem recently described in the literature is to measure CTDI\(_{vol}\) by scanning the CTDI phantom helically.\(^3\) Although eminently practical and providing consistent results appropriate for quality control (QC) checks, there are systematic scatter contribution differences between this approach and the definition of CTDI\(_{vol}\). Presented is a method to determine CTDI\(_{vol}\) consistent with its definition on helical scan protocols by directly measuring CTDI\(_w\) on the helical scan.
FIGURE 1  Positioning of body phantom with brackets. Shown is the body CTDI phantom suspended on the GE Discovery CT gantry shroud and above the scanner tabletop with brackets. The brackets were originally developed at UAB 20 years ago to facilitate long helical exposure times for CT environmental radiation surveys.

2 MATERIALS AND METHODS

The body CTDI phantom was modified by the addition of brackets to the sides of the phantom. The brackets (Support Bracket, Model 007-01, CIRS, Norfolk, VA), support the phantom on the CT gantry shroud with the tabletop below. One attaches the brackets to the phantom, centers the phantom in the gantry by adjusting the tabletop height and position, adjusts the lengths of the brackets so that they are in contact with the gantry shroud, and lowers the tabletop 1 to 2 cm below the phantom. As shown in Figure 1 the body CTDI phantom is supported by the brackets and gantry shroud. These brackets have been used on CTs at our institution for more than two decades and have never damaged the gantry shroud. Even though the CTDI body phantom itself is large, the CT gantry is constructed to withstand large forces, and has no problem with the apparatus. Additionally, the rubber feet prevent the brackets from scratching the shroud.

During a helical scan the tabletop moves and the phantom remains stationary. One measures the surface and axis exposures associated with the helical scan. The measured exposures are divided by the number of gantry rotations during the scan, \( N_{\text{rot}} \), to determine values for one rotation, and CTDI\(_w\) is calculated. The number of gantry rotations is given by

\[
N_{\text{rot}} = \frac{\text{Helical scan distance}}{(\text{Table movement per rotation})}
\]

(1)

The helical scan distance is the distance the tabletop travels while the x-ray beam is on and was determined from the technical information associated with the scan or by dividing the displayed DLP (dose-length-product) by the displayed CTDI\(_\text{vol}\). Alternatively, the number of rotations can be determined by dividing chamber exposure time by the rotation time. Exposure per rotation may be calculated as:

\[
X_{\text{rot}} = \frac{X_{\text{measured}}}{N_{\text{rot}}}
\]

(2)

where \( X_{\text{rot}} \) is defined as the exposure per rotation, \( X_{\text{measured}} \) is defined as the exposure measured during an entire acquisition, and \( N_{\text{rot}} \) is the number of rotations in the acquisition. This method was first used in the acceptance test of a recently installed Siemens Somatom Drive CT scanner that did not have axial scan protocols with the same detector configurations as those employed in the helical protocols. To confirm the validity of the method, CTDI\(_w\) and CTDI\(_\text{vol}\) were measured with the adult body and head CTDI phantom for helical and axial scans on a GE Discovery CT scanner, employing the same detector configuration and technical factors. Shown in Figure 2 is the head CTDI phantom positioned in the center of the Siemens gantry for a helical (and axial) CTDI\(_w\) acquisition. The head holder is removed and phantom is taped to a 6.35 mm (1/4") thick lauan...
TABLE 1  Comparison of axial and helical CTDI\(_w\) acquisitions and CTDI\(_{vol}\) determinations on GE Discovery CT scanner with body (32 cm diameter) CTDI phantom

| Scan FOV | Large body | Large body |
|----------|------------|------------|
| X-ray tube potential (kV) | 120 | 120 |
| X-ray tube current (mA) | 250 | 250 |
| Rotation time (s) | 0.6 | 0.6 |
| Axial (A) or helical (H) | H | A |
| Pitch | 0.984 | 1.0 |
| Number of rotations | 5.92 | 1.0 |
| Measured CTDI\(_w\) (mGy) | 11.06 | 11.11 |
| Measured CTDI\(_{vol}\) (mGy) | 11.24 | — |
| Displayed CTDI\(_{vol}\) (mGy) | 12.22 | — |
| Displayed/measured CTDI\(_{vol}\) | 1.09 | — |

TABLE 2  Comparison of helical and axial CTDI\(_w\) acquisitions and CTDI\(_{vol}\) determinations on GE Discovery CT scanner with head (16 cm diameter) CTDI phantom

| Scan FOV | Head | Head | Head |
|----------|------|------|------|
| X-ray tube potential (kV) | 120 | 120 | 120 |
| X-ray tube current (mA) | 250 | 250 | 250 |
| Rotation time (s) | 1.0 | 1.0 | 1.0 |
| Axial (A) or helical (H) | H | H | A |
| Pitch | 0.531 | 0.969 | 1.0 |
| Number of rotations | 10.064 | 5.587 | 1.0 |
| Measured CTDI\(_w\) (mGy) | 46.13 | 45.87 | 46.38 |
| Measured CTDI\(_{vol}\) (mGy) | 86.88 | 47.19 | — |
| Displayed CTDI\(_{vol}\) (mGy) | 93.95 | 51.52 | — |
| Displayed/measured CTDI\(_{vol}\) | 1.081 | 1.092 | — |

plywood board attached to the same brackets that are employed for the body CTDI\(_w\) measurements.

In this study, for axial scans, if the table increment between rotations is the same as the beamwidth, the pitch is defined as 1. If the table increment between rotations is greater than the beamwidth, the pitch is greater than 1. Likewise, if it is less, the pitch is less than 1.

3 | RESULTS

As noted above this method was first used on a Siemens Somatom Drive CT scanner. The difference between the measured CTDI\(_{vol}\) and the value displayed by the scanner is 2% for the head and 5% for the body. Table 1 lists the helical and axial body CTDI acquisitions made on the GE Discovery CT. The measured CTDI\(_w\) values acquired with the two scan protocols agree to within 1%. Table 2 lists helical (two scans with different pitches) and axial head CTDI acquisitions made on the GE Discovery unit. The coefficient of variation of the three CTDI\(_w\) measurements is 0.7%. In addition, the axial head CTDI\(_w\) was measured with the head phantom supported by the GE head holder rather than by the lauan board. The axial measurement with the head holder agreed with the suspended phantom measurement to within 1%. Table 3 lists helical and axial head CTDI acquisitions made on a Siemens Somatom Drive CT scanner. The agreement of the two head CTDI\(_w\) values is within 1.5%. We would therefore recommend between 5 and 10 rotations to minimize error.

4 | DISCUSSION

The Siemens Somatom Drive CTDI\(_w\) head axial and helical results match within 1.5%. The results for the GE Discovery body axial and helical CTDI\(_w\) are within 0.5%. The good agreement for the axial and helical results validates the suspended phantom method. This is not unexpected as the CTDI phantom is stationary for both the axial and helical scan protocols. The only differences are: (1) the tabletop moves in one case and not the other; (2) exposure times are longer for helical than for axial scans; and (3) in helical scans the dosimeter reading is for several rotations while in axial scans the dosimeter reading is for one rotation (one divides the helical reading by the number of rotations to determine the result for one rotation).

Critical to the direct helical CTDI\(_w\) measurements is determining the number of rotations associated with the helical scan. For the measurements presented, this was determined by dividing the scan distance by the tabletop movement per rotation. Over-ranging occurs at the start...
and end of helical scans, and it is important to note that the scan distance is greater than the distance spanned by the reconstructed images. An alternative approach to determine the number of rotations is to measure the x-ray exposure time with the ion chamber or separate sensor during the helical scan and divide the exposure time by the rotation time.

Both the GE and Siemens CT scanners on which the above measurements were made are ACR accredited. For the GE scanner, axial dosimetry measures were submitted. For the Siemens scanner, the suspended CTDI phantom method was employed and the helical dosimetry readings divided by the number of rotations were submitted.

Leon et al. propose a helically acquired CTDI\textsubscript{vol} as an alternative to making axial CTDI\textsubscript{w} measurements to determine CTDI\textsubscript{vol}, and that its use is appropriate for QC purposes.\textsuperscript{3} The helically acquired CTDI\textsubscript{vol} is much easier and more time-efficient than CTDI\textsubscript{vol} determined with the suspended phantom method. However, as noted by Leon et al., it is not a perfect match for the traditionally determined CTDI\textsubscript{vol} measured with the CTDI phantom stationary, as the scatter contributions are different. This is due to the fact that the CTDI phantom is bounded by air, which does not attenuate and scatter radiation to the same extent as acrylic will. As the phantom moves out of the beam, less radiation is scattered back into the phantom and the detector than would be for a corresponding slice in the middle of the CTDI phantom. In our practice, on scanners where axial scans with the same pre-patient filtration and detector configurations employed on helical protocols are not available, we plan to measure initially both the helically acquired CTDI\textsubscript{vol} and the suspended phantom measured CTDI\textsubscript{vol}, and develop a correction factor. Subsequently for routine QC we will measure the helically acquired CTDI\textsubscript{vol} and use the correction factor to make the measurement more representative of the traditional CTDI\textsubscript{vol} determination.

Our method may also be useful in the measurement of cone-beam CBDI as well (defined as in ref.\textsuperscript{4}). Mobile cone-beam units may also move during acquisition,\textsuperscript{5} meaning an adaptation of this method may be useful.

5  |  CONCLUSIONS

The good agreement of axial and helical results for the GE Discovery scanner (CTDI body and head phantoms) and for the Siemens Somatom Drive scanner (CTDI head phantom) demonstrates that the suspended phantom method is viable and allows one to directly measure CTDI\textsubscript{w} and CTDI\textsubscript{vol} with helical scans.

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CONFLICT OF INTEREST
The authors declare no conflict of interest.

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